

ON CAUSES AND CONSEQUENCES OF TRAFFIC ACCIDENTS

**A study based on findings from
investigations into fatal accidents**

PETER KRANTZ



LUND 1984



ON CAUSES AND CONSEQUENCES OF TRAFFIC ACCIDENTS

**A study based on findings from
investigations into fatal accidents**

PETER KRANTZ



**DEPARTMENT OF FORENSIC MEDICINE
University of Lund
Lund, Sweden**

MORTUI VIVOS DOCENT

This dissertation is based on the following publications:

- I. Krantz K.P.G. Differences between single- and multiple-automobile fatal accidents. *Accid. Anal. & Prev.* 11, 225-236 (1979)
- II. Krantz K.P.G., Wannerberg O. Occurrence of barbiturate, benzodiazepine, meprobamate, methaqualone and phenothiazine in car occupants killed in traffic accidents in the South of Sweden. *For. Sci. Int.* 18, 141-147 (1981)
- III. Krantz K.P.G., Löwenhielm C.G.P. Injury response in belted and unbelted car occupants related to the car crash energy in 458 accidents. *Proc. V Int. IRCOBI conf.* Birmingham, 305-317 (1980)
- IV. Löwenhielm C.G.P., Krantz K.P.G. The effect of the unrestrained back seat passenger on the injuries suffered by drivers and front seat passengers in head-on collisions. Accepted for publication in *Z. Rechtsmed.*
- V. Krantz K.P.G. Head and neck injuries to motorcycle and moped riders - with special regard to the effect of protective helmets. Submitted to *Injury*.
- VI. Krantz K.P.G., Löwenhielm C.G.P. Effect of protective helmet mass on neck axial force in head impact. Submitted to *J. Biomech. Eng.*

In the text, these papers will be referred to by their Roman numerals.

CONTENTS

INTRODUCTION	4
METHODOLOGICAL CONSIDERATIONS	6
SUMMARIES OF THE PAPERS	8
Paper I	8
Paper II	9
Paper III	10
Paper IV	11
Paper V	12
Paper VI	13
GENERAL DISCUSSION	14
CONCLUSIONS	23
ACKNOWLEDGEMENTS	24
REFERENCES	25

- o -

APPENDIX: Papers I - VI



INTRODUCTION

The aim of traffic safety research is to reduce the number of accidents and mitigate their consequences in terms of deaths, injuries and economical losses to the individual and society. There are many causes of traffic accidents and concomitantly different protective measures have been introduced.

One concept of modern automobile design is safety and this has resulted in seatbelts, deformation zones of the automobiles, improved bumpers and better windscreens etc. Not only the "protected" automobile occupants benefit from these measures, but also to some extent the "unprotected" road users such as mc- and moped-riders, cyclists and pedestrians. Protective helmets further reinforce the safety of two wheel riders.

Traffic safety requires driving skills and responsible behaviour from the road user. However, a socially deviant person, who perhaps will drive under the influence of alcohol and drugs, is not easily impressed by safety measures.

Laws have been passed to make certain safety measures compulsory. In 1967 when Sweden changed from left-hand to right-hand traffic, the number of traffic casualties which had been continuously rising, showed a downward trend. At the same time, rigorous speed limits were introduced and information about traffic safety was intensified. The mandatory use of seat belts was introduced in 1975 and from this year on, a sharp decline in the number of traffic casualties was noticed. The substantial increase in fuel prices during the last decade may have contributed to the decline in the number of traffic accidents.

The combined efforts to enhance traffic safety have been a success. But follow-up studies of the existing protective measures are necessary if further developments are to be made in this field. In-depth analyses of specific problems are important, so that unexpected failures of "good intention" are not overshadowed by the total positive picture. In this context, investigations of real accidents constitute a valuable source of information.

One important problem in most investigations of traffic and traffic accidents is the access to data; it is often difficult to obtain consecutive series of certain types of accidents which will inevitably mean that the data will be biased. According to Tolagen (1977), about 50% of the seriously injured traffic casualties are not taken up in official statistics.

The material available at the Departments of Forensic Medicine in Sweden is unique in the sense that it is devoid of these shortcomings. First it is complete, as it comprises all traffic fatalities in southern Sweden (1.8 million inhabitants), second it is well defined, as it is a sample of the most severe accidents, third it is thoroughly investigated, as meticulous postmortem investigations are made of all cases by trained

forensic pathologists and the autopsies are followed up by laboratory tests for alcohol and drug in all cases where this is possible, and finally the autopsies are uniformly evaluated, as the examinations are performed by a small group of forensic pathologists.

Traffic accident material of this kind and the opportunity to supplement it with information from criminal and social records offers a powerful tool in the investigation of various causes and consequences of serious traffic accidents. Some of these aspects have been chosen and the aim of the present study may be summarised as follows:

- To study the frequency of inebriation among drivers involved in serious automobile accidents;
- To study the frequency of drivers influenced by psychoactive drugs involved in serious automobile accidents;
- To study some of the personality traits of drivers involved in serious automobile accidents;
- To study the protective effect of safety belts on automobile occupants involved in serious traffic accidents;
- To investigate the possible effect of unrestrained back seat occupants on the injuries suffered by the front seat occupants;
- To study the causes and appearances of the different head and neck injuries suffered by riders of motorized two-wheel vehicles;
- To investigate the influence of protective helmets on these injuries suffered by riders of motorized two wheel vehicles.

METHODOLOGICAL CONSIDERATIONS

Some of the methods and features of the material on which this study is based are only briefly described in the papers. A further presentation follows:

Autopsy cases at the Department of Forensic Medicine in Lund

In Sweden, all victims killed in accidents are remitted to the regional department of forensic medicine for autopsy (there are 6 such departments in the country). This is the case not only for the victims killed instantly but also for those who die in hospital independent of the surviving time. The rule is: all cases in which trauma cannot be excluded as a cause of death are remitted. In a very few cases in the northern part of the country, autopsies were performed by local pathologists. At the autopsy, police reports from the accident in question including photographs from the scene of the accidents and the vehicles involved as well as hospital records were available. The post mortem examinations were supplemented by chemical analyses for alcohol and psychoactive drugs. At the Department of Forensic Medicine in Lund, the upper part of the cervical spine and the head-neck junction were always examined at autopsies according to the methods proposed by Sköld (1978). In order to examine the parasagittal bridging veins, the brain was always removed *ad modum Flechsig* (Voigt and Saldeen, 1968).

The criminal record

One of the papers (I) is based on information from the Swedish Central Criminal Data Record which consists of two data-based records. One of them called the criminal record, is designed to give information about more important crimes and penalties in each separate case to guide the courts when passing sentence. Crimes that only render fines are not recorded. The information in the record is erased ten years after the last entry.

The other record, the central police record, includes all information from the criminal record as well as crimes rendering fine penalties (in Sweden the fines are assessed on the basis of the defendant's daily income). Violations are included as well as convictions for drunk driving. Trivial offences, such as parking offences are not recorded. This record is designed for use by the police. The crimes with fine penalties are erased 5 years after the last entry and the rest of the information ten years after the last entry. In cases of new crimes, the former information is retained in both records. The central police record was used as the source of information for the findings in Paper I

The social records

In Sweden, the social record is not a state register but a municipal one. Adults are registered in this record for

offences against the law of temperance i.e. repeatedly being visibly drunk in the streets or other public places or because of untreatable chronic alcoholism. Persons receiving financial support from the municipal authorities are likewise registered. Young persons are registered mainly because of acts of juvenile delinquency defined in the law of child welfare. In 1975, the period of study for Paper 1, the level of unemployment was very low, and thus very few received financial support, a fact of importance regarding the number of persons registered.

The criminal as well as the social records are secret and information for this investigation was obtained after special permission.

Alcohol tests

In Sweden, alcohol tests on drivers are performed in the following cases: 1. Drivers of motorized vehicles who are stopped in routine controls decided in advance by the police authorities. 2. Drivers involved in traffic accidents. 3. Drivers suspected of exceeding the speed limits, not stopping at stop signs, offences against the obligation to drive with the vehicle lights on. The breathalyzer is used as a screening test. If the result is positive, blood alcohol tests are performed. The source for the figure regarding drunk drivers mentioned in the summary of Paper II is a result of random samples according to case 1 above.

SUMMARIES OF THE PAPERS

Differences between single- and multiple- automobile fatal accidents (I)

In order to increase the knowledge about performance and behaviour of automobile drivers involved in serious accidents, all accidents with fatal outcome during one year in Sweden (1975) were examined. Special attention was focused on differences and similarities between single- and multiple-vehicle accidents (SVA and MVA) with regard to 1. the traffic conditions at the accident scene, 2. the course of the accidents and 3. the personality of the drivers, including possible drunk driving.

SVA mostly took place on weekends and at night, whereas MVA occurred mainly during the afternoon rush hours. In SVA contrary to in MVA, bad weather played no significant role. Skidding before impact was more common in SVA than in MVA. In most cases, the former accidents took place on roads with a speed limit of 70 km/h while MVA often occurred on roads with a speed limit of 90 km/h.

Considering the general age distribution of the licenced drivers in the country, the young drivers were overrepresented. SVA-drivers were significantly younger than those drivers involved in MVA. The mean age among SVA-drivers was 34 and the median age was 29. The corresponding figures for MVA-drivers were 42 and 38.

Eighty-eight percent of fatally injured SVA-drivers and 78 % of fatally injured MVA-drivers were tested for blood alcohol concentration. Out of these, 50 % of fatally injured SVA-drivers and 12 % of fatally injured MVA-drivers had a blood alcohol concentration exceeding 0.05 %. No MVA involved more than one inebriated driver.

Drunk driving is regarded as a sign of social deviance in Sweden. The established difference concerning inebriation in the two categories of drivers called for further investigation referring to other signs of social deviance. In this analysis, the killed as well as the surviving drivers were studied. In accordance with the law of child welfare and the law of temperance persons are registered in the social record. Persons depending on social welfare are registered as well. Juvenile delinquency is the main reason for registration according to the law of child welfare. Persons are registered in the criminal record according to the traffic code or the criminal penal code. The convicted drivers were recorded in the criminal record because they had committed various crimes which could be divided into the groups: felonies, drunk driving and traffic violation. Among SVA-drivers 27% were registered in the criminal record and 30% in the social record. Judging by the reason for their registration, SVA-drivers had more severe social and criminal problems than MVA-drivers.

If one of the conditions: 1. registered in the social record, 2. registered in the criminal record and 3. drunk in the accident were fulfilled the driver was considered as socially deviant. More than 50 % of killed and surviving SVA-drivers complied with this definition compared with the 20 % frequency among killed and surviving MVA-drivers and few possessed a driver's licence. Alcoholic problems were common and among the inebriated drivers 64 % were registered in social and/or criminal records and many of the drunk drivers were considered chronic alcoholics. The frequency of seat belt use was low. A higher percentage of drivers involved in MVA were licenced and their use of seat belts was also more frequent.

Thus, the features of SVA-drivers differ significantly from MVA-drivers even when the results are corrected with regard to the fact that there are always two drivers involved in collisions between vehicles. Thus 50 % of the drivers in these accidents supposedly represent what could be called average drivers.

The findings indicated that many SVA-drivers showed socially deviant personality traits and it would appear that some of them might be persons with various types of psychopathic states.

Occurrence of barbiturate, benzodiazepine, meprobamate, methaqualone and phenothiazine in car occupants killed in traffic accidents in the south of Sweden (II)

Alcohol is regarded as one of the major causes of traffic accidents but there is some doubt concerning drug-affected behaviour as a cause of traffic accidents. Although some psychoactive drugs are known to decrease driving ability, the frequency of different types of road users under the influence of such drugs is unknown. Drunken drivers are greatly over-represented among drivers involved in accidents compared with the frequency of inebriation among drivers checked at random. Accordingly, one would expect a high frequency of drugged drivers involved in fatal accidents if drug influence really is an important cause of traffic accidents.

Paper II is a report of analyses of the drugs barbiturate, benzodiazepine, meprobamate, methaqualone and phenothiazine in all car occupants killed in traffic accidents in southern Sweden during a two-year period. Of 122 investigated drivers, 28 (23%) solely were inebriated. Two were under the influence of both alcohol and minor amounts of methaqualone and benzodiazepine. In 7 of the non inebriated drivers, the results were positive for meprobamate (2 drivers), methaqualone (1 driver), benzodiazepine (3 drivers) and both methaqualone and benzodiazepine (1 driver). In these 9 accidents, there were only 3 cases in which drug influence might have been of importance as the cause of the accident.

The findings of Paper II suggest that drug use is a minor problem compared with alcohol as a cause of severe traffic accidents.

Injury response in belted and unbelted car occupants related to the car crash energy in 458 accidents (III)

The use of seat belts is generally regarded as a useful means of reducing the severity of injuries and to save lives in car crashes. Consequently, seat belt use is compulsive in many countries. Mandatory seat belt use was introduced in Sweden on January 1, 1975. In an attempt to evaluate the protective properties of seat belts, all automobile accidents in the whole country in which a car occupant was killed during this year were investigated. A multifactorial approach was made and included information on the type of accident, the age of the car occupants, their positions in the car, complete knowledge of the injuries as well as an estimate of the impact energy. Knowledge about the impact energy is of crucial importance when comparing the injuries of the restrained car occupants and those of the unrestrained ones. The impact speed would offer the best information about impact energy but is unobtainable. The deformation of the cars involved in the accidents formed the basis for an estimate of the impact energy. The degree of deformation was graded and used as a qualitative tool for the selection of comparable accidents.

The severity of the injuries was graded according to the Abbreviated Injury Scale (AIS) and the Injury Severity Score (ISS). A comparison of the injuries to killed victims and surviving occupants showed a lethal ISS level of 25 which roughly corresponds to the severity of injuries observed in unrestrained front seat occupants in a collision, at a speed of about 45 km/h.

Injuries to the head and neck were more frequent and severe among unrestrained occupants than among restrained ones. Likewise, rupture of the aorta, liver and spleen as well as lung contusions were observed in a higher frequency among unrestrained occupants. However, fractures of the iliac crest were somewhat more frequently observed among restrained occupants. In these results, the impact energy was not taken into account.

The causes of death in delayed fatalities (i.e. persons who died in hospital and up to 1 year after the accident in question) showed that the number of potentially salvageable deaths was low.

Only 46 % of the car occupants under 25 years of age used seat belts compared with 71 % of those over 50 years of age. The severity of the injuries was also strongly correlated to the age of the victims. Despite the fact that the young front seat occupants as a group were involved in accidents with a higher estimated impact energy, they showed lower ISS figures.

In head on collisions and to some extent in impacts against the

contralateral side of the car compared with the occupant under study, lower ISS-values were observed in restrained front seat occupants compared with unrestrained front seat occupants. Restrained drivers showed higher ISS values compared with restrained front seat passengers in head on collisions, probably due to the negative effect of the steering assembly.

As mentioned above, the degree of deformation of the involved cars was chosen for calculation of the relative impact energy. In accidents with low and moderate estimated impact energy, an average difference of about 10 ISS units between the restrained and the unrestrained crash victims was shown. For high energy accidents, the difference of the ISS scored injuries tended to decrease. In these accidents, the extensive deformation of the car reduces the effect of seat belts.

It is difficult to compare injuries suffered by those ejected from the car and those suffered by those not ejected, as the "environmental" factors are not comparable. However, by taking the relative impact force into account, it was possible to make a comparison. It was evident that the ejected occupants showed considerably higher values of ISS than those confined to the car.

Fatalities caused by seat belts were extremely rare. Even if a seat belt is used, the steering assembly and dashboard remain a threat to life in head-on collisions. It is likely that the head will hit these parts of the car while the torso is restrained by the belt.

The greatest quality of the seat belt as regards life saving is probably in preventing an ejection from the vehicle in an accident.

The effect of the unrestrained back seat passenger on the injuries suffered by drivers and front seat passengers in head-on collisions (IV)

Whereas in Sweden the use of seat belts is mandatory for front seat occupants, this is not the case for back seat passengers. In head-on collisions loose items in the rear of the car can cause considerable loading on the back of the front seats. The aim of Paper IV was to study if the extra load of unbelted back seat occupants could increase the number and severity of the injuries suffered by the front seat occupants in automobiles.

The investigated series consisted of all head on collisions occurring in the whole of Sweden in 1975 in which an occupant was killed. In 101 of 398 front seat occupants, there was an unrestrained back seat occupant behind the driver or the front seat passenger. The impact energy, reflected by the degree of deformation of the car (Paper III), was taken into consideration in the evaluation of the possible harmful effect of unrestrained back seat passengers.

The studied front seat occupants were grouped according to their position in the car and their use of seat belts. Though the groups were small, the results indicate that for collision speeds below 45 km/h, restrained front seat passengers are exposed to a higher injury risk with an unrestrained passenger in the back seat. In high speed collisions, this is probably also the case for front seat passengers. In these types of accidents, the driver will often sustain severe injuries because of impact against the steering assembly. The effect of the extra loading of an unrestrained back seat passenger is probably overwhelmed by the deformation of the car in such accidents and seems thus to be of minor importance for the injuries to the driver.

Head and neck injuries to motorcycle and moped riders
-with special regard to the effect of protective helmets (V)

Improvements of road systems and vehicles concomitant with the use of protective devices like seat belts have reduced the number of fatalities in automobile accidents. There are limited possibilities to protect riders of motorized two-wheel vehicles (mtwv) in accidents though, and coherent with the increase in the number of motorcycles, the number of killed mc riders has increased. Despite the somewhat diminishing number of killed moped riders the total figure of mtwv casualties has increased during the last few years. In these accidents, the most common cause of death is head and neck injuries. Paper V is an analysis of these injuries and an evaluation of some effects of protective helmets.

All 132 moped and mc riders killed during a period of 7 years in southern Sweden were scrutinized as to head and neck injuries. When available, the helmets were examined as well. Ninety-seven percent of mc riders wore helmets while the corresponding figure for moped riders was 50%.

Almost half of the fatal head and neck injuries appeared remote from the point of head impact. Certain intracranial injuries without fractures, ring fractures of the base of the skull, disruption of the head-neck junction and cervical spine injuries constituted these remote injuries which mostly were the result of frontal impact against the head. Ring fractures of the base of the skull were observed in a remarkably high frequency.

Despite helmet use, many riders suffered fractures and cerebral lesions at the point of impact. In these cases, the points of impact were mostly found in the lateral-posterior part of the head especially in a zone around the head equivalent to that of a hatband.

It is doubtful whether the helmets offer any protection against the above mentioned injuries situated remote from the point of impact. The finding that of 6 riders suffering disruption of the head-neck junction all were helmeted, might indicate that the helmets can promote such injuries. A whip-lash mechanism of

the head enhanced by the weight of the helmet is supposed to be the cause of some of the fatal injuries sustained by these riders.

The helmets should be improved in order to give better protection against local injuries caused by indentation of the helmet shell at the point of impact. The energy-absorbing capacity must increase as well. The frequent cases of impact against the unprotected part of the face, with injuries located remote from the point of impact, indicate the need for some measure of energy absorption in this part of the head. However, these improvements must not entail an increase in helmet mass, as this probably would result in injuries being transferred from the point of impact to the region of the head-neck junction.

Effect of protective helmet mass on neck axial force in head impact (VI)

To test the assumption that increased helmet mass will increase the forces in the head-neck junction in cases of head impacts (c.f. Paper V), an experimental investigation was performed.

A wooden dummy head with the same weight as a human head (i.e. 5 kg) was linked to a dummy torso with an inter-connecting 3-axial force transducer. The dummy head sustained a lateral blow by means of an impact piston. Impact speed and force were recorded as well as the forces generated in the junction between the dummy head and the torso. The test was repeated with helmets of different weight and design.

Increased helmet mass was found to increase the axial force in the neck. Tests with polycarbonate thermoplastic shells resulted in higher peak magnitude of the impact force and axial force in the neck interpreted as indentation of the helmet shell with the unyielding dummy head. Thus, the stiffness of the helmet shell may also be of importance for the magnitude of the axial forces of the neck.

GENERAL DISCUSSION

Research into traffic accidents of today has to be based on in-depth analyses of specific problems. The aim of this study is to elucidate some of the causes and consequences of serious traffic accidents. The selection of the material studied is of crucial importance in such an investigation. The present material of series of accidents with fatal outcome seems to be suitable for this purpose: It is clearly defined, it is complete in that all, or in one of the series almost all, of the killed victims have been investigated. Furthermore, the accident scene and the events of the accidents were thoroughly investigated. The fatal casualties were examined post mortem by a small group of trained forensic pathologists resulting in a uniform judgement.

To cover all causes and consequences in traffic accidents in one investigation is not possible. This study attempts to deal with this complex problem by in depth analysis of some questions suitable for the material available. Causes such as personal characteristics, possible influence of alcohol or drugs and driving behaviour of the drivers involved in severe accidents are discussed in Paper I and II. Information on the general circumstances in the accident is given in Paper I, III and V. Paper III, IV, V and VI deal with appearances and causes of the inflicted body injuries. The effect of protective devices on the frequency and severity of the injuries is also studied in Paper III, IV, V, VI.

Causes of traffic accidents

It is essential to know whether "accidents" really are accidents or whether certain types of people are more liable to be involved than others. It is also important to consider the driving ability and the effect of different factors like alcohol, drugs or mental distress on the likelihood of a person being involved in traffic accidents.

It is well known that young drivers are overrepresented in traffic accidents compared with the general age distribution of licensed drivers. Opinions about other definitions of accident-prone drivers vary. According to some authors, drivers with a heavy social and criminal burden are also overrepresented in traffic accidents (Tillman and Hobbs, 1949, Kraus et al., 1970, Suchman, 1970). In Paper I, social deviance was defined as complying with one or more of the following conditions: 1. registered in the social record, 2. registered in the criminal record, 3. drunk in the accident. About 50 % of the drivers involved in single-vehicle accidents fulfilled this definition as compared with only 20 % of the drivers in collisions between vehicles. Two thirds of the drunk drivers involved in single-vehicle accidents were registered in the social and/or criminal record.

Drunk driving is a well-known cause of traffic accidents and numerous investigations have been carried out on this subject. However, the frequency of drunk driving depends on the kind of sample of drivers studied:

In random tests only a few drivers per 1000 tested were inebriated (SCB, 1983).

Among surviving or only slightly injured drivers involved in accidents, drunk driving was found in 11% according to Dalgaard (1977).

In a population of drivers severely injured in traffic accidents, 21 % had a blood alcohol concentration exceeding 0.05 % (Tolagen 1977). From Finland, Honkanen and Visuri (1976) and from Switzerland, Padrutt (1979) have reported even higher frequencies of inebriation. However, a lot of cases "slip through the net" in these types of investigations.

Drivers killed in accidents constitute a well defined group. Consecutive studies are possible in countries where post mortem investigations are routinely performed on all such victims. In a study by Dalgaard (1977), alcohol analyses were made in 83 % of the cases. Thirtyone percent had been driving under the influence of alcohol. This agrees with both the general figures for Sweden, where 31.5 % of these killed drivers were found to be drunk (SOU, 1970), and the results of the present investigation (Paper I): Drunk driving was found in 29.6 % of the killed drivers. The frequency of inebriation among these drivers is, thus, somewhat less than 1/3.

However, in single-vehicle accidents where the driver was killed, the frequency of drunk driving was 50% (Paper I). This also agrees with findings in other countries (Haddon and Bradess, 1959, Honkanen, 1976, Tonge et al., 1977)

A continuous follow-up of the results - from 1975 - has been performed on all traffic fatalities in the southern part of Sweden. The frequency of drunk driving among the drivers killed in single vehicle accidents during the last 3 years is in 1981: 7 out of 18, (39 %), in 1982: 8 out of 18, (44 %) and in 1983: 10 out of 19, (53 %). These samples are too small for conclusions regarding the trend and according to figures from the Swedish Road Safety Office (1983) there are no signs of change in the frequency of drunk driving among drivers killed in traffic accidents.

Driving under the influence of drugs is also believed to be a cause of traffic accidents. There are experimental data that support this opinion (Linnoila, 1976, Staak, 1976). The knowledge about the real importance of drug influence as a contributory factor in the cause of traffic accidents is surprisingly little. In spite of this, it is illegal to drive under the influence of drugs in Sweden. Furthermore, since the beginning of 1983, drugs which are believed to affect driving ability are labeled accordingly by law.

Yet, information about the magnitude of the problem is essential. If psychoactive drugs, like alcohol, are important as a cause of traffic accidents, one would expect a fairly high frequency of these drugs in the selected group constituted by the killed drivers. A few investigations of this kind have been carried out in the USA (Davis, 1974, Turk et al., 1974, Woodhouse, 1975, Garriott, 1977). In approximately 10 % of the drivers involved in accidents, some sort of drugs were detected, and in another 10 % both drugs and alcohol were found. The findings presented in Paper II showed that psychoactive drugs were found in 7.3 % of the killed drivers - a somewhat smaller figure compared with the findings mentioned. Five psychoactive drugs were searched for as, in cases of hospital treated intoxications during the studied period, they were found in an overwhelming frequency. Consequently, the findings differ depending on the country where the investigations are carried out.

The circumstances concerning the events in these accidents, indicated that drug influence might have been a contributory factor in very few of the cases. Recently, another similar investigation on traffic casualties in the south-west part of Sweden was published (Jacobson et al., 1983). A considerably larger number of drugs were analysed, but the results were similar to those presented in Paper II. At present, driving under the influence of drugs must be regarded as a minor cause of traffic accidents. This does not rule out that new trends might appear.

It has been suspected that single-vehicle accidents might be concealed suicides. In the present material, the usually occurring hints of suicidal intention were not present in any case. This problem is extremely difficult to investigate. A different approach was made by Phillips (1977) who investigated a number of single vehicle accidents in California shortly after articles in the press about suicides committed by famous persons. The frequency of established suicide cases is known to increase under these circumstances. So did the number of single vehicle accidents. However, this finding is an indirect proof and can not be taken for granted in Sweden.

The driver involved in serious traffic accidents, especially in single-vehicle accidents, was very often young, with signs of social deviance (drunk driving). One might regard these features as lack of judgement and a parallell may be drawn to the increasing number of young motorcycle riders on the roads many of whom are injured or killed in accidents.

General environmental conditions and the time of the day when serious traffic accidents occur are wellknown from official statistics. Data presented in Paper I concerning single-vehicle accidents differed from these figures in the sense that these accidents took place during weekends, late at night on small roads and were independent of weather conditions. The results support the opinion that the drivers involved were deviants.

Injuries sustained in traffic accidents

Despite vigorous efforts to reduce the number of accidents, they will always happen. Consequently, it is necessary to know the number and severity of the injuries among the victims in order to adapt trauma care, develop optimal safety measures and follow up countermeasures to accidents and injuries which have already been instituted. General descriptions of the injuries appearing in traffic accidents have been published internationally as well as in Sweden, among others by Bäckström (1963) and Tolagen (1977). To gain information about the origin of different injuries in accidents or the protection offered by seat belts and helmets, it is necessary to have a more specific approach.

One factor that substantially influences the injury severity is the violence of the accident, i.e. the impact energy. The effect of the safety devices will also depend on this energy. Numerous attempts have been made to determine the energy level in real accident cases. The impact speed, or rather the change in speed during impact, would have been a useful tool but it is not obtainable. In the present study, the degree of deformation has been used to estimate the energy level although it was well understood that this technique can only give an approximate value. A similar technique has been used by Langwieder (1973) and Bolin (1977) who have studied the degree of car deformation at different speeds and also studied the injuries to the occupants. In this way, it is possible to estimate the impact energy by analysing car deformation (Langwieder, 1973).

It is also necessary to have a well defined material to be able to carry out a study. The investigations presented in Papers III and IV were based on a complete one year material of all victims in automobile accidents in the whole of Sweden in which one or more occupants were killed. Autopsies were performed in 97 % of the cases. The surviving occupants were also included and information about them was obtained from hospital case records.

As an aid for comparison of different injuries, Baker et al. (1974) proposed the wellknown Abbreviated Injury Scale (AIS) which has been revised and completed with a system for scoring of the overall injury, the Injury Severity Score (ISS) (Baker and O'Neill, 1976, Committee on injury scaling, 1980). By using the AIS and ISS, the injuries (occurring in different types of accidents and by different types of victims) were scored. The degree of the car damage was used to estimate the relative impact energy and the injuries of the victims were evaluated. In this way, victims involved in accidents of similar severity could be compared.

It was shown that young front seat passengers as a group were involved in more serious accidents compared with older persons, but suffered less serious injuries i.e. there is a strong age dependency of the number and severity of the injuries. This agrees with the findings of Baker and O'Neill (1976).

This difference is explained by the better reaction ability, greater muscle strength, when holding on to interior car details when trying to protect themselves, of young people. Further the breaking strength of the tissues is highest during the third decade (20 -24 years) of life (cf. Yamada, 1970).

The ensued injuries might also depend on where the occupant is seated in the vehicle. In Paper III, it was shown that drivers generally suffered more severe injuries to the head and thorax probably due to the steering assembly compared with other occupants.

In cases of accidents, certain details in the cars, like loose items in the rear of the car, can cause considerable loading on the back of the front seats in head-on collisions. The extra load caused by an unrestrained back seat passenger on a restrained occupant sitting in front of him in such collisions, is believed to increase the injuries of the latter (Bolin, 1977). The problem in evaluating such an effect lies in obtaining series of comparable head-on collisions large enough for analysis as the number of accidents involving back seat passengers is relatively low. By estimating the impact energy, it is possible to compare the injuries appearing in accidents of different severity. The results from Paper IV indicated that restrained front seat passengers, with an unrestrained passenger in the back seat, sustained a higher risk of injuries in head-on collisions at a moderate impact speed. Among drivers, the deleterious loading effect is probably overwhelmed by the deformation of the car and perhaps contact with the steering assembly.

There are also other hazards in addition to the risk of being injured inside the car. Ejection from the car in the accident is generally regarded to be most dangerous (Huelke, 1977). By using the method described on the impact energy estimation, the injuries sustained by those ejected could be compared with those confined to the cars in accidents of similar severity (Paper III). The injuries in the former group, in which nobody used seat belts, were much more severe.

According to official statistics (SCB, 1983), most casualties in traffic accidents are automobile occupants. Nevertheless, there are other road users. Paper V concentrates upon the riders of motorized two wheel vehicles (mtwv) mainly because the number of motorcycles has risen during the last years and the number of accidents with severe injuries to the riders is becoming a serious problem. The number of mopeds has remained unchanged (Mätzsch, 1983). In traffic mtwv-riders are less protected than automobile occupants.

Mc-riders and many moped riders are also young which is of some importance when discussing the injuries appearing in accidents among these persons. The most common cause of death among mc and moped riders is injuries to the head and neck (Graham, 1969, Mätzsch, 1983). Some of the injuries, such as total disruption of the parasagittal bridging veins depend on the age

of the rider and mainly occur in young riders (Voigt and Löwenhielm, 1974). However, the strength of, for instance, bone tissue decreases with age and this explains the more extensive fractures in older mtwv-riders (Yamada, 1970)

Preventive measures

As traffic accidents are still a major problem owing to the frequency and severity of the injuries among the victims and the economical losses to individuals and society as a whole, many counter measures have been introduced. However, it is necessary to evaluate the effect of these in order to improve them and come up with new ideas.

One way of preventing severe accidents may be to describe groups of high risk drivers in accordance with the findings of this study. Robertson and Baker (1975) agreed that there are accident prone socially deviant drivers but according to them the group is too big for special preventive measures. Suchman (1970) thought that the problem was that this kind of persons was unresponsive to official information. As the number of single-vehicle accidents has risen in 1983 in Sweden (SCB, 1983), preventive measures must be taken.

What can be done? Stiffer penalties for previously committed crimes may keep these persons off the road for a while, but it is known that such a measure has little effect upon this type of persons (SOU, 1971). More stringent demands for acquiring a driver's licence or disqualification if a crime is committed will be equally ineffective. This conclusion can be drawn from the numerous socially deviant drivers without a license in the present material. Notwithstanding the above proposals above by Suchman (1970) and Robertson and Baker (1975) it might be possible in Sweden to diminish the number of fatalities in this group of relatively young persons by means of different types of information to young individuals and the high risk group under study. A similar proposal was put forward by the committee on Human Factors in Road Accidents (SOU, 1971)

It is difficult to tell if the increased awareness among drivers about the alcohol-induced impairment of driving ability and the increased risk of involvement in accidents have played any role in the reduction of fatal accidents during the last years. If so, one would expect a decrease in the total number of accidents yet, an unaffected frequency of drunk drivers involved in the accidents. This is, in fact, what has happened.

Preventive devices

Traumatic injuries depend on many factors; force, contact time, properties of the body area involved as well as the properties of the object hit by the body. In a real accident situation, direct contact with the interior of the automobile, e.g. wind-screen, steering assembly, dashboard etc. give rise to forces of considerable magnitude. Therefore, reduction of the impact

force, enlargement of the impact area, increase of the contact time and energy dissipation are essential parameters in the design of safety systems. As to car occupants, seat belts are regarded as one of the most effective protective measure. In numerous investigations (Andreasson and Roos, 1977, Bäckström, 1959, Cameron and Nelson, 1977, Dalgaard, 1977, Huelke et al, 1979, Nordentoft, 1977, Robertson, 1976, Shanks and Thompson, A.L. 1979, Tolagen, 1977) the injuries to restrained occupants were compared with the injuries to unrestrained occupants. Different positive factors for the effectiveness of seat belts have been proposed. However, there is a risk of bias when comparing accidents of different degrees of severity with each other, if the impact energy is not taken into consideration in the evaluation. This problem was discussed by Dalgaard (1977).

The findings in Paper III clearly showed that there was a positive effect on the injuries if a seat belt was worn in accidents with low and moderate impact energy. For accidents of higher impact energies, the difference of the ISS scored injuries suffered by restrained and unrestrained front seat occupants diminished. This is to be expected as the deformation of the car gradually becomes greater as a consequence of the increased impact energy, the protective effects of seat belts diminish accordingly. It was also found that in head-on collisions the restrained drivers showed more severe injuries than the restrained front seat passengers. This difference was probably caused by contact with the steering assembly. To some extent it could be explained by stretching of the loaded seat belts and the tested pyrotechnic rotary belt tightener that is released in a collision (Hontschik et al. 1977) may reduce this problem.

As unrestrained back seat occupants increase the risk of injury to front seat passengers the demands for mandatory seat belt use for back seat occupants is not only important for their own protection, but equally important for the protection of the front seat occupants (Paper IV).

The possibilities of increasing the protection for mtwv riders are very limited. The use of protective clothing and helmet are regarded as two of the few possible countermeasures to injuries at the moment (Engström, 1979).

Numerous investigations have shown a general positive effect of the use of helmets (Watson et al., 1980, Heilman et al., 1982) and as a parallel to the mandatory use of seat belts for car occupants in Sweden, the use of protective helmets became compulsory on September 1, 1977.

Discussing the helmet influence on injuries, four characteristics of the helmet are of great importance: 1. the shell resistance against penetration, 2. the capacity of the lining to reduce the impact energy, 3. the capacity of the shell as regards skidding and 4. the effects of the helmet weight. The two first characteristics are well-known and have been taken into consideration in the formulation of the American and

European helmet standards. Good skidding properties are important in reducing rotation of the head (head angular acceleration) and have been investigated by Glaister (1984). A helmet adds about 20 % extra weight to the weight of the head. In cases of trauma against the head, this will inevitably influence the loading of the head-neck junction. Owing to the complex nature of the events in mc accidents, it has been very difficult to show, though some writers have suspected the fact, that such a loading could produce or at least modify the appearance of injuries in cases of accidents. (Davydov and Nirenburg, 1978, Sorgo, 1978, Aldman et al., 1979, Hurt, 1979).

In an evaluation of the effect of the helmet weight in cases of impact against the head, it would have been purposeful to be able to estimate the impact energy. The method of grading impact energy described for automobile accidents (Paper III) cannot for obvious reasons be adapted to mtwv accidents. A case by case study of a consecutive series of accidents is the only fruitful way of revealing the mechanism of the occurring injuries.

When discussing head-impact, it is necessary to bear in mind that injuries occur not only at the point of impact, but also in remote tissue. Injuries at both locations represent a potential threat to life. In Paper V almost half of the victims sustained severe head and neck injuries remote from the point of impact. These injuries were seen as ring fractures of the base of the skull, disruption of the head-neck junction, cervical spine injuries and as certain intracranial lesions without fractures.

The protective effect of helmets upon these types of injuries is difficult to evaluate. According to Huston and Sears (1981), the mass of the helmet decreases the angular acceleration and thus, diminishes the risk of disruption of the parasagittal bridging veins. They also propose that an increased helmet weight will enlarge the movement angle of the head and thus increase the risk of injuries to the neck. According to Paper VI, increased helmet mass produced a higher traction force in the head-neck junction when the head received a lateral blow. It is likely that these results are valid in blows from other directions, too. It is worthwhile mentioning that one specific type of injury, disruption of the atlanto-occipital joint, was only observed in helmet wearers.

The result from Paper VI and the results from the investigation on the killed riders indicate that the helmet weight is of importance and can contribute to deleterious injuries to the head-neck junction.

From the investigation of the killed mtwv-riders, it was also shown that despite the resistant helmet shell there were numerous cases suffering severe injuries at the point of impact. The reason is quite clear; in many mc accidents the impact energy is far beyond the protective limits of the helmet.

Trauma care

After an accident, effective trauma care is essential in order to reduce the number of killed victims and to reduce possible late effects of the injuries. Much has been said about the number of potentially salvageable traffic casualties. In a WHO report (1968), it was claimed that 15 % of road deaths were due to respiratory obstruction and thus potentially salvageable. However, the source of information was not given. Such a statement reflects the system of trauma care studied. In Paper III it was shown that 72 % of all killed cases were beyond all medical care as they were immediately killed at the scene of the accident. The causes of death among the delayed fatalities was investigated and the findings indicated that the WHO figure of 15 % of salvageable victims in road accidents is far too high. This has also been confirmed in a further study on this subject by Ottosson and Krantz, (1984).

Predictions

It is difficult to predict what will happen in the field of traffic accidents and casualties. Increasing social problems due to the rising number of young persons out of work constitute a risk for social deviance and may influence the number of traffic accidents. During the last 15-20 years, automobiles have become safer, but the demands on low fuel consumption have led to a trend towards smaller automobiles. In cases of impact, deformation in such cars will increase the risk of injury to the occupant. More young motorcycle riders are likely to be killed and injured if the number of these vehicles on the road continues to increase.

CONCLUSIONS

- * Drunk driving is an important factor in the cause of fatal automobile accidents. Many of the drivers involved in such accidents, especially drivers in single-vehicle accidents, are inebriated. This can be compared with the fact that only a few drivers per thousand checked in routine controls are found to be driving under the influence of alcohol.
- * Driving under the influence of psychoactive drugs does not seem to be a major cause of fatal automobile accidents.
- * More than 50% of the drivers involved in fatal single-vehicle accidents show signs of social deviance.
- * The frequency of camouflaged suicides among the single vehicle accidents is difficult to assess, but is probably fairly low.
- * In cases of accidents, the most beneficial effect of the lap-shoulder seat belt is that it prevents ejection from the automobile.
- * In accidents with low and moderate impact speed, the seat belt diminishes the number and the severity of the injuries. The beneficial effect is less pronounced for the driver due to the risk of impact with the steering assembly.
- * Despite the fact that young car occupants are involved in more serious accidents, they are not as seriously injured as elderly persons.
- * In head-on collisions, unrestrained back seat occupants increase the risk for injuries to the occupant sitting in front of them.
- * Head and neck injuries are the most common cause of death among riders of motorized two wheel vehicles.
- * Nearly half of the head and neck injuries in the killed riders are located remote from the point of impact. Ring fractures of the base of the skull are common.
- * Injuries located remote from the point of impact mostly follow impact against the frontal part of the head, especially the face.
- * Fatal head injuries at the point of impact are also found among wearers of protective helmets.
- * Increased weight of the helmet increases the traction force in the neck when the head suffers a lateral blow.
- * Protective helmets seem to increase the risk of some injuries located remote from the point of impact, especially disruption of the head-neck junction.

ACKNOWLEDGEMENTS

I wish to express my gratitude to:

Professor Gerhard Voigt, my teacher, for introducing me to the field of research on traffic accidents and for neverfailing support and advice throughout this study.

Associate Professor Peter Löwenhielm for enthusiastic collaboration, help and friendship.

Mrs. Doris Nilsson for outstanding help with illustrations and lay-out.

Mrs. Margareta Lindman for support and co-operation.

Mr. Jonathan Thornton for kind interest and revision of my English.

My colleagues and the staff of the Department of Forensic Medicine for the sacrifices they have made in helping me with this study.

REFERENCES

- Aldman, B. et al. The protective effect of crash helmets. A study of 96 motorcycle accidents. Proc. IV Int. IRCOBI Conf. Göteborg, 63, (1979)
- Andreasson, R., Roos, K. Effects of Sweden's seat belt law. Opmeer. 22, 57. (1977)
- Baker, S., O'Neill, B. The injury severity score; an update. J Trauma 16, 882, (1976)
- Baker, S. et al. The injury severity score: A method for describing patients with multiple injuries and evaluating emergency care. J Trauma 14, 187, (1974)
- Bolin, N. 15 years with the three-point safety belt. Proc. 6th Int. Conf. of IAATM, Melbourne (1977)
- Bäckström, C-G. Säkerhetsbälten i bilar. Nord. Med. 62, 1667, (1959)
- Bäckström, C-G. Traffic injuries in South Sweden. Acta Chir. Scand. Suppl. 308. (1963)
- Cameron, M.H., Nelson, P.G. Injury patterns with and without belts. Proc. 6th Int. Conf. of IAATM, 423. Melbourne (1977)
- Committee on injury scaling: The abbreviated injury scale 1980 revision. Morton Grove, Illinois, American Association for Automotive Medicine. (1980)
- Dalgaard, J.B. Draebt i bil. Ulykkesårsager og selevirkning. En trafikmedicinsk undersøgelse. Rådet for trafiksikkerhedsforskning, Rapport 21, (1977)
- Dalgaard, J.B. et al. Experiences with the new seat belt law. Proc. 6th Int. Conf. of IAATM, Melbourne (1977)
- Davis, J.H. Carbon monoxide, alcohol, and drugs in fatal automobile accidents, Dade county, Florida, 1956 - 1968. Clin. Toxicol. 7, 597, (1974)
- Davydov, E.A., Nirenburg R.K. The effect of protective helmets and head guards on damage to the skull and brain in cranio-cerebral trauma. Zh. Vopr. Neurokir. 5, 13, (1978)
- Engström, A. Causes and consequences of moped and motorcycle accidents. Scand. J. Soc. Med. suppl. 15 (1979)
- Garriott, J.C. et al. Incidence of drugs and alcohol in fatally injured motor vehicle drivers. J. Forensic. Sci. 22, 383, (1977)
- Glaister, D.H., Mortimer, P. A test for the "sliding resist-

ance" of protective helmets. To be presented at the Int. IRCOBI Conf. Delft, (1984)

Graham, J.W. Fatal motorcycle accidents. J. For. Sci. 14, 79, (1969)

Haddon, Jr. W., Bradess, V.A. Alcohol in the single vehicle fatal accident. JAMA 169, 127, (1959)

Heilman, D.R. et al. Motorcycle-related trauma and helmet usage in north Dakota. Ann. Emerg. Med. 11, 659, (1982)

Honkanen, R., Visuri, T. Blood alcohol levels in a series of injured patients with special reference to accident and type of injury. Ann. Chir. Gynaecoll. Fenn. 65, 287, (1976)

Hontschik, H. et al. Necessities and possibilities of improving the protective effect of three-point seat belts. Proc. 21st Stapp Car Crash Conf. SAE paper 770933, (1977)

Huelke, H.W. et al. Effectiveness of current and future restraint systems in fatal and serious injury in automobile crashes. Proc. 23rd Stapp Car Crash Conf. SAE paper 790323, (1979)

Hurt, H.H. Motorcycle accidents cause factors. DOT-HS-5-01160, (1979)

Huston, R.L., Sears J. Effect of protective helmet mass on head/neck dynamics. J. Biomech. Eng. 103, 18, (1981)

Jacobson, B. et al. Alcohol and drugs in road traffic accident victims. J. Traffic Med. 11, 28, (1983)

Kraus, A.S. et al. Pre-driving identification of young drivers with a high risk of accidents. J. Safety Research 2, 55, (1970)

Langwieder, K. Passenger injuries in collisions and their relation to general speed scale. Proc. 17th Stapp Car Crash Conf. SAE paper 730963, (1973)

Linnoila, M. Tranquilizers and driving. Acc. Anal. & Prev. 8, 15, (1976)

Mätzsch, T. Injuries in moped- and motorcycle accidents - a five-year-series. Läkartidn. 80, 2514, (1983)

National Central Bureau of Statistics. Road traffic accidents with personal injury. Stockholm (1983)

Nordentoft, E.L. et al. Effect of mandatory seat belt legislation in Denmark with special regard to minor and moderate injury. Proc. 6th Int. Conf. of IAATM, Melbourne (1977)

Ottosson, A., Krantz, P. Traffic fatalities in a system with decentralized trauma care. A study with special reference to potentially salvageable casualties. Accepted for publication in JAMA, (1984)

Padrutt, M. Analyse von 609 Alleinunfällen im Strassenverkehr in der Landschaft Zurich mit besonderer Berücksichtigung des Alkoholeinflusses. Inaugural-dissertation. Medizinischen Fakultät der Universität Zurich, (1979)

Phillips, D.P. Motor vehicle fatalities increase just after published suicide stories. Science 196, 1464, (1977)

Robertson, L.S., Baker S.P. Prior violation record of 1447 drivers involved in fatal crashes. Acc. Anal. & Prev. 7, 121, (1975)

Robertson, L.S. Estimates of motor vehicle seat belt effectiveness and use: Implications for occupant crash protection. Am. J. Publ. Health 66, 859 (1976)

SCB. Year book of judicial statistics 1982. National Central Bureau of Statistics, Stockholm, (1983)

SCB. Road traffic accidents with personal injury 1982. National Central Bureau of Statistics, Stockholm, (1983)

Shank, J.E., Thompson, A.L. Injury mechanism to fully restrained occupants. Proc. 23rd Stapp Car Crash Conf. SAE paper 791003, (1979)

Sköld, B.G. On the genesis of ring fractures of the base of the skull and fractures of the vertebral column, especially of atlas and accis. Academic dissertation, University of Lund, (1978)

Sorgo, G. Neue Erkenntnisse bei der Verwendung des Sturzhelmes. Beitr. Ger. Med. 36, 395, (1978)

SOU. Trafiknykterhetsbrott. Statens Offentliga Utredningar, Stockholm, (1970)

SOU. Committee on human factors in road accidents. Statens Offentliga Utredningar, Stockholm, (1971)

Suchman, E.A. Accidents and social behaviour. J. Health Soc. Behav. 11:4, 4, (1970)

Staak, M., Mallach, H-J., Moosmayer, A. Untersuchungen über die Auswirkungen von Oxazepam und Alcohol auf die Verkehrstüchtigkeit. Beitr. Gerichtl. Med. 34, 91, (1976)

Swedish Road Safety Office. Intern PM no 295. (1983)

Tillman, W.A., Hobbs, G.E. The accident-prone driver. A study of the psychiatric and social background. Am. J. Psychiatry Nov. 321, (1949)

Tolagen, A. Trafikskadade i östergötland. Universitetet i Linköping Medicinska Fakultet No 46, (1977)

Tonge, J.I. et al. Traffic-crash fatalities (1968 - 1973): Injury pattern and other factors. Med. Sci. Law. 17, 9, (1977)

Turk, R.F., McBay, A.J., Hudson, P. Drug involvement in automobile driver and pedestrian fatalities. J. Forensic Sci. 19, 90, (1974)

Voigt, G.E., Saldeen, T. Ueber den Abriss zahlreicher oder sämtlicher Vv. cerebri sup. mit geringem Subduralhaematom und Hirnstammsläsion. Dtsch. Z. ges. gerichtl. Med. 64, 9, (1968)

Voigt, G.E., Löwenhielm, C.G.P. "Gliding contusions" des Grosshirns. H. Unfallheilk. 117, 329, (1974)

Watson, G.S., Zador P.L., Wilks A. The repeal of helmet use laws and increased motorcyclist mortality in the United States, 1975 - 1978. Am. J. Public Health 70, 579, (1980)

WHO report on a Symposium on human factors in road accidents, Rome, October 1967. Regional Office for Europe of the WHO, Copenhagen (1968)

Woodhouse, E.J. The incidence of drugs in fatally injured drivers. Vth Int. Conf. IAATM, September 1975.

Yamada, H. Strength of biological materials. Evans, F.G., Ed. Baltimore, Williams & Wilkins (1970)

DIFFERENCES BETWEEN SINGLE- AND MULTIPLE-AUTOMOBILE FATAL ACCIDENTS

PETER KRANTZ

Department of Forensic Medicine, University of Lund, Sölvegatan 25, S-223 62 Lund, Sweden

(Received 1 August 1978; in revised form 31 January 1979)

Abstract—This communication discusses probable similarities and differences between single-vehicle and multiple-vehicle accidents. The investigation is based upon all fatal automobile accidents in the whole of Sweden [1975]. It is shown that single-vehicle accidents are more common on weekends and late in the day. Collisions between vehicles occurred often during bad weather conditions. Single-vehicle accidents happened more often on roads with lower speed limits than did collisions between vehicles. In single-vehicle accidents the drivers were markedly younger, more often drunken, and showed severe signs of social deviance. These features of the drivers in single-vehicle accidents significantly differed from drivers involved in collisions between vehicles even when results were corrected with regard to the fact that there are always two drivers involved in collisions between vehicles, and thus 50% of the drivers in these accidents supposedly represent what could be called average drivers. The use of seat belts and possession of driver's licenses were much lower in single-vehicle accidents. The question of psychopathic states in drivers involved in single-vehicle accidents is raised.

Traffic accidents resulting in injuries of car occupants may be single-vehicle accidents, i.e. involvement of only one moving car, or collisions, i.e. participation of two or more moving cars. In earlier investigations [Haddon, 1959; Tolagen, 1977; Tonge *et al.*, 1977; Vaughan, 1975] concerning the cause of automobile accidents interest has been focused on either both groups or on single-vehicle accidents only. In the last-mentioned type of accident the high frequency of drunken driving is striking [Haddon, 1959; Honkanen, 1976; Tonge *et al.*, 1977]. The mean age of the drivers involved in single-vehicle accidents is low [Dalgaard, 1977; Tonge *et al.*, 1977; Vaughan, 1975] and the accidents occur more frequently on weekends [Dalgaard, 1977; Tolagen, 1977; Tonge *et al.*, 1977; Vaughan, 1975]. In the available literature no study comparing single- and multiple-vehicle accidents could be found showing probable differences or similarities between them with regard to the traffic conditions at the accident scene, the course of the accidents, and the personality of the drivers, including possible drunken driving. The present investigation is based upon all fatal automobile accidents in the whole of Sweden in 1975 and deals with such a comparison.

MATERIAL AND METHOD

Official statistics in Sweden are based upon police-reported accidents, but there is no immediate official reporting system concerning fatal and other severe road accidents. For the actual investigation the collection of the material was based on daily newspaper reports sampled by the Authority of Traffic Safety and upon reports from all the Departments of Forensic Medicine in the country. According to a decree by the central police department, all traffic fatalities should be autopsied at Departments of Forensic Medicine. The material consists of 209 single automobile accidents and 249 collisions between vehicles in which at least one automobile occupant has been killed. According to our information from the Authority of Traffic Safety, the number of fatal accidents of this type in 1975 should be 468, and thus the number of accidents not included in the present material is very small.

In the above-mentioned 458 accidents, 560 occupants of automobiles were killed. In all cases police reports and photographs of the accident scenes and of the cars involved as well as autopsy reports on 542 (97%) of the victims were obtained. Furthermore, all reports concerning toxicological analyses (blood alcohol) and medical reports concerning all investigated or treated surviving participants in the accidents have been analysed. Driving license records and social and criminal records revealed information concerning the previous social behaviour of the drivers involved in the accidents. Data obtained by police and medical reports have been

verified and supplemented by personal interviews of witnesses. For judgement of possible statistical significance the χ^2 -test was used.

RESULTS

In the 209 single-vehicle accidents (209 drivers) there were a total of 542 occupants including the drivers, and in the 249 collisions between vehicles there were 395 automobiles (395 drivers), in all 824 occupants including the drivers. Altogether there were 604 automobiles with 1366 occupants. Of these, 140 drivers and 89 passengers were killed in single-vehicle accidents, and 188 drivers and 143 passengers in multiple-vehicle accidents. Sixty-nine drivers survived single vehicle accidents, and 207 drivers collisions between vehicles.

Types of accidents

In 77 cases (37%) of the single-vehicle accidents the cars impacted against a tree or post. In 35 cases (17%) the cars impacted against a bank or drove into a ditch. In the remaining 95 cases (47%) the cars collided with stationary vehicles, stones, rocks, barriers, house walls, etc. In only 2 cases (1%) did the cars collide with animals, in both cases elks. In the multiple vehicle collisions, 145 automobiles impacted against other automobiles, 86 against lorries, and 18 against trains. Regarding rollovers, there are great differences between single-vehicle accidents and multiple-vehicle collisions. Single-vehicle rollover occurred primarily when the car drove into a ditch or hit a bank (30 cases) or impacted against a pole (26 cases). Rollover after primary impact occurred in 109 cases (52%) of the single-vehicle accidents, as opposed to only 18 cases (7%) of the multiple-vehicle collisions. Rollover very rarely occurred after collisions between automobiles and lorries or buses.

Time of accident and existing weather conditions

The distribution throughout the year of single-vehicle accidents and collisions between vehicles is fairly even, with a slight decrease of both types of accidents in April and September.

The distribution of the accidents during the week is shown in Fig. 1. Accident frequency increased on weekends. This is especially notable concerning single-vehicle accidents where 122 (58%) of the accidents occurred between Friday and Sunday. The corresponding figure for multiple-vehicle collisions is 116 (46%). The distribution of the accidents according to the time

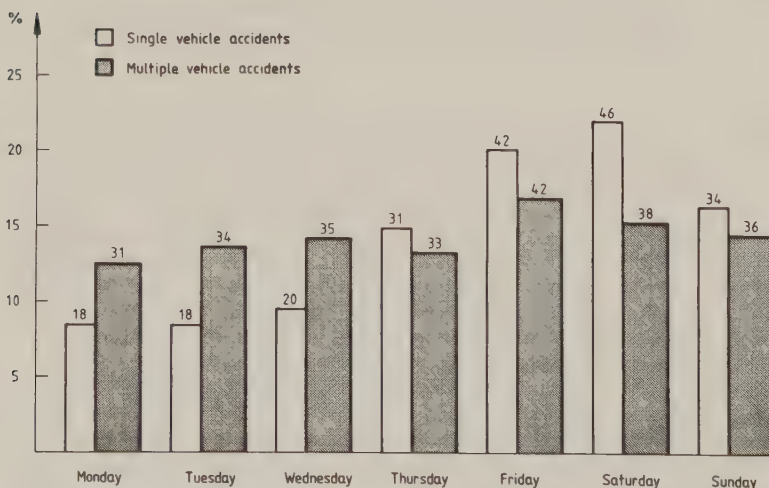


Fig. 1. Distribution of fatal single- and multiple-vehicle accidents in Sweden 1975 during the week. The height of the histograms indicate the percentage of accidents in the two accident groups respectively and the figure at the top of the histograms the absolute number of accidents.

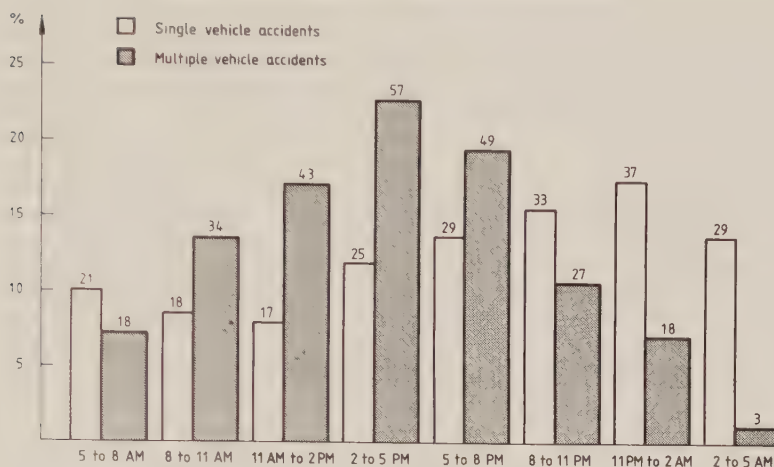


Fig. 2. Distribution of fatal single- and multiple-vehicle accidents in Sweden 1975 according to the time of day. The height of the histograms indicate the percentage of accidents in the two accident groups respectively and the figure at the top of the histograms the absolute number of accidents.

of day is shown in Fig. 2. The accident rate for single-vehicle accidents between 4 and 6 p.m. was only 34 (17%) and the corresponding rate for multiple vehicle accidents was 68 (27%). Thirty-seven (18%) of the single-vehicle accidents occurred between 11 p.m. and 1 a.m. while only 18 (7%) of the multiple-vehicle collisions took place during this time.

Single-vehicle accidents took place in darkness in 101 cases (48%) compared with 76 cases (31%) of collisions between vehicles. Only a few accidents occurred at dawn or dusk, and in these cases there is little difference between the two groups. Multiple-vehicle collisions occurred more commonly during daylight.

Two hundred and sixty-seven (58%) of the accidents occurred during clear weather, 125 (27%) when the sky was clouded, and 14 (3%) when it was foggy. Only 34 (7%) occurred in rain, and 19 (4%) when it was snowing. The percent distribution on single- and multiple-vehicle collisions does not differ in clear or clouded weather; however, 46 (18%) of the multiple-vehicle collisions occurred during poor weather conditions such as rain, snow, or fog, as opposed to only 20 (10%) of the single-vehicle accidents.

Accident scene

In Sweden all roads are speed limited. The limits are 50, 70, 90 and 110 km/h (31, 43, 56 and 68 mph). As could be expected, most (378 cases or 83%) of these severe accidents took place on roads that permitted a speed of more than 50 km/h (31 mph). Collisions between vehicles (98 cases or 39%) on roads with a 90 km/h (56 mph) speed limit were relatively more frequent than single-vehicle accidents (73 cases or 35%). On the other hand, multiple-vehicle accidents on roads with a 70 km/h (43 mph) speed limit were relatively less frequent (86 cases or 41%) compared to single-vehicle accidents (79 cases or 32%). In 16 cases (8%) of the single-vehicle accidents and 26 cases (10%) of the multiple-vehicle collisions took place on highways or other roads with a speed limit of 110 km/h (68 mph).

Regarding road surface, 101 single-vehicle accidents (48%) and 122 multiple-vehicle collisions (49%) happened on dry asphalt. Twenty-three single-vehicle accidents (11%) and 48 multiple-vehicle collisions (19%) occurred on wet asphalt. Forty-two single-vehicle accidents (20%) and 50 multiple-vehicle collisions (20%) took place when snow or ice was on the road. Single-vehicle accidents occurred more frequently on dry gravel (26 cases, 12%) than did multiple-vehicle collisions (14 cases, 6%). Otherwise, the distribution of the two groups of accidents on the different road surfaces is fairly even.

In single-vehicle accidents 108 cars (52%) skidded before impacting. Regarding collisions

between vehicles, one of the two vehicles involved skidded before colliding in 70 cases (28%).

In 32 single-vehicle accidents (15%) and in 68 multiple-vehicle collisions (27%) the visibility at the scene was reported as reduced due to curves, hills, trees, etc. In most cases (162 accidents or 78%) of single-vehicle accidents and of multiple-vehicle collisions (179 or 72%) the visibility at the scene was reported as good.

Vehicles

The types of automobiles involved in the accidents were compared to the total number of registered automobiles of the same type in Sweden in 1975. There were no significant differences to be seen in this comparison.

In 67 automobiles the police suspected technical defects and arranged for a thorough investigation of the vehicles by officers of the Government Authority of Traffic Safety. Technical defects considered to be responsible for the causing of the accidents have been observed in 10 cases. Of 29 examined cars in single-vehicle accidents, 4 vehicles were defective. The corresponding figure in multiple-vehicle collisions was 6 defective cars of 38 examined.

Drivers

Driver's age. The drivers involved in the accidents have been divided into 7 groups according to their age. These groups have been compared with the total number of the licensed drivers in the country (Fig. 3). In single-vehicle accidents the largest group consists of drivers between 21 and 30 yr of age and the second largest group consisted of those between 16 and 20 yr of age. The older the driver, the less involvement in single-vehicle accidents. Thus, 116 (55.5%) of all drivers involved in single accidents were younger than 30 yr of age. In collisions between vehicles the largest group consists of drivers between 21 and 30 yr of age. However, in multiple-vehicle accidents the number of drivers between 16 and 20 yr of age is much smaller (40 drivers, i.e. 10%) than the corresponding figure in single-vehicle accidents. The number of drivers younger than 30 yr of age involved in collisions between vehicles was 116 (29%). In single-vehicle accidents the involvement of elderly drivers (71 yr or older) was very uncommon

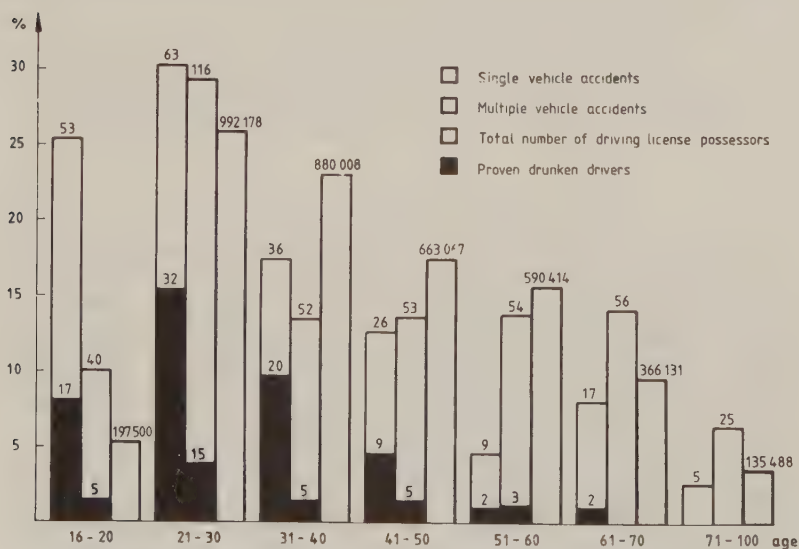


Fig. 3. Distribution of the drivers involved in fatal single- and multiple-vehicle accidents in Sweden 1975 according to their age and degree of inebriation compared with the total number of licensed drivers in the same age-groups in Sweden 1975. The height of the histograms indicate the percentage of the drivers in each group and the figure at the top of the histograms the absolute number of drivers in this group.

(5 drivers, 2%), but such persons were more often (25 drivers, 6%) involved in multiple-vehicle collisions.

Drivers' age and the type of accident. Single-vehicle accidents could be divided into 11 different groups according to the type of accident. The most common situation was driving (to the right) off a straight thoroughfare. This happened in 69 cases (33%). Other common situations in single-vehicle accidents were driving to the left off a straight road (32 cases, 15%), driving off at the outside of a curve to the right (20 cases, 10%), or to the left (36 cases, 17%); driving off at the inside of a curve to the right (8 cases, 4%), or to the left (16 cases, 8%), or rolling over on a straight road (8 cases, 4%). The age distribution of the drivers in these types of accidents did not differ from the general age distribution among licensed drivers. In collisions with stationary vehicles, however, 4 drivers out of 12 were older than 65 yr of age and only 5 were younger than 25 yr of age. Cell sizes in the remaining three groups, driving off at crossings, colliding with fixed objects such as poles, stones, etc. or colliding with animals, were too small for meaningful comparison.

The collisions between vehicles could be divided into 5 main groups and 16 different subgroups according to the type of accident. These main groups were head-on collisions (242 drivers, 61%), collisions between a car turning off from a main road and an oncoming or following vehicle (46 drivers, 12%), collisions in crossing (77 drivers, 19%), collisions with trains (18 drivers, 5%) and collisions between cars driving in the same direction, for example, overtaking (13 drivers, 3%). The subgroup, rear-end collisions, was included in the group last-mentioned and was very small in this sample. The accidents were distributed fairly evenly among the above-mentioned age groups and collision types. It is worth mentioning, however, that in collisions occurring when the driver is turning left at a *T*-junction with an impact from the right and in collisions at crossings with an impact from the right, 19 out of 29 and 30 out of 66 drivers respectively were older than 55 yr of age.

Drunken driving

Of 276 drivers surviving the accidents, 69 drivers were involved in single-vehicle accidents and 207 drivers in multiple-vehicle collisions. Of the surviving drivers blood alcohol tests were performed on 25 (36%) of the drivers involved in single-vehicle accidents and on 27 (13%) of the drivers in multiple-vehicle collisions. The results of the analyses have been corrected by adding 0.015% alcohol per hour for the time between the accident and the time of blood sampling. In most cases the time between the accident and the blood sampling was about 2 hr, but in 4 cases the time exceeded 3 hr. In one case the time delay was 7.5 hr and the amount of alcohol proven was 0.05%. In order to facilitate comparison with American studies, figures for uncorrected alcohol concentrations are given as well. In single-vehicle accidents 20 (80%), uncorrected value 17 drivers (70%), of the investigated surviving drivers had an alcohol concentration of more than 0.05%. The corresponding number in multiple-vehicle collisions was 13 (48%) of the investigated surviving drivers with regard to both corrected and uncorrected analysis results. Of the 140 fatally injured drivers in single-vehicle accidents and the 188 fatally injured drivers in multiple-vehicle collisions, blood alcohol tests were performed on 123 (88%) of the drivers involved in single-vehicle accidents and on 147 (78%) of the drivers involved in multiple-vehicle collisions. Sixty-two of the drivers fatally injured (50%) in single-vehicle accidents were shown to have been driving under the influence of alcohol (uncorrected analysis results more than 0.05%). The corresponding figure for multiple-vehicle collisions was 18 (12%). Concerning multiple-vehicle collisions, there was no case where more than one of the involved drivers was proven to be under the influence of alcohol. The age of the drivers under the influence of alcohol is shown in Fig. 3. In both types of accidents, driving under the influence of alcohol was most common in drivers between 21 and 30 yr of age, and in single vehicle accidents driving under the influence of alcohol was also common among the drivers between 31 and 40 yr of age.

Social background

In Sweden, persons are entered in social records in accordance with the law of child welfare, the law of temperance, or if extraordinary financial support is given, on account of social misery. The social record is not a state register but a municipal one. Juvenile delinquency

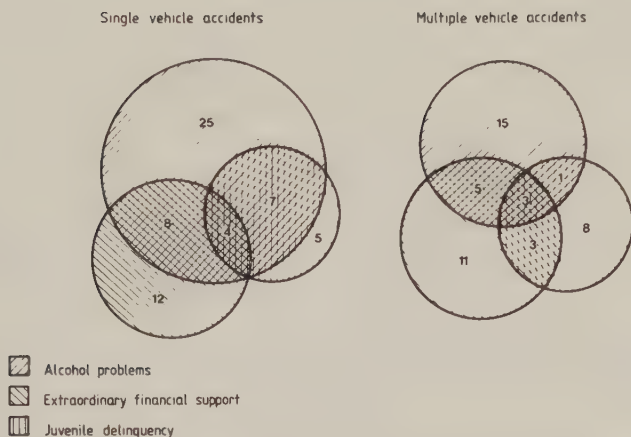


Fig. 4. Registration in social records for 200 drivers involved in single vehicle accidents and 383 drivers involved in collisions between vehicles. The numbers within the circles represent the absolute number of drivers in the two accident types in each group. Totally there are 61 registered drivers in single-vehicle accidents, and 46 in collisions between vehicles. For example it can be seen that 4 drivers in single-vehicle accidents are registered because of their alcohol problems, their receiving extraordinary financial support and their juvenile delinquency.

is the main reason for registration of young people (up to the age of 18 yr) according to the law of child welfare and is the reason for including them into this investigation.

Drunken driving, repeatedly being visibly drunk in the streets or other public places, and untreatable chronic alcoholism are the main reasons for registration according to the law of temperance.

Receiving financial help or support from the municipal authorities in another reason for registration in the social records.

In 200 of the 208 drivers involved in single-vehicle accidents, and in 383 of the 396 drivers involved in multiple-vehicle collisions, we were able to examine the social record. As seen in Fig. 4, as many as 61 of 200 (30%) drivers involved in single-vehicle accidents were registered because of alcoholic problems, juvenile delinquencies, and/or financial difficulties. Of 383 drivers involved in multiple-vehicle collisions, 46 (12%) were registered.

As regards drivers involved in single vehicle accidents, it was found that many of these showed signs of having severe social problems, by the fact that several of these were found to be persistent offenders. Thus, not less than 11 out of 16 drivers with juvenile delinquencies have also been registered because of alcoholic problems. This trend is less marked concerning drivers involved in multiple-vehicle collisions.

Criminal background

Records of prior criminal violations. (i.e. violation before the accident) have been obtained from the Central Criminal Data Record (C.C.D.R.) for the above-mentioned 200 drivers involved in single-vehicle accidents and 383 drivers involved in collisions between vehicles. Thus, all offences convicted by courts are available. Fifty-four of the 200 drivers (27%) in single-vehicle accidents were registered with C.C.D.R., as compared to 46 of 383 drivers (13%) involved in multiple-vehicle collisions. The drivers were convicted according to the traffic code or the criminal penal code. Various crimes were committed, including minor traffic offences such as exceeding speed limits or lack of automobile insurance; but also serious offences such as drunken driving, burglary, receiving stolen property, car theft, forgery, narcotics crimes, possession of unlicensed arms, murder and arson. If the different violations are placed into the groups; felonies, drunken driving and traffic violation, the result is shown in Fig. 5. As shown, over half of all convicted drivers involved in single-vehicle accidents have been convicted more

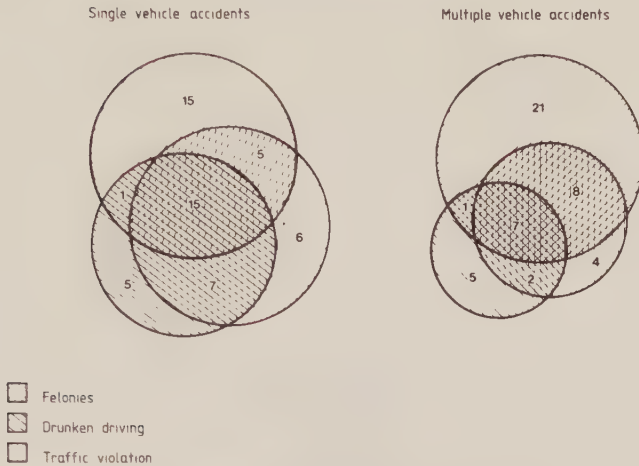


Fig. 5. Registration in the Central Criminal Data Record of 200 drivers involved in single-vehicle accidents and in 383 drivers involved in collisions between vehicles. The numbers within the circles represent the absolute number of drivers in the two accident types in each group. Totally there are 54 drivers registered in single-vehicle accidents, and 48 drivers in collisions between vehicles. For example, it can be seen that 15 drivers in single-vehicle accidents are registered on account of felony, drunken driving and violation of other traffic laws.

than once. Of 100 previously convicted drivers only 4 are female—one involved in multiple-vehicle collision and three in single-vehicle accidents. Two of these three female drivers had been convicted for drunken driving and one had been convicted for selling stolen goods. The female driver involved in a collision between vehicles had been convicted for a minor traffic violation and also for driving without a license.

The Central Criminal Data Record was started in 1959, and the crimes committed before this year are registered in unavailable local records.

Regarding penalty, prison is seldom used as punishment in Sweden and sentences of more than five months in prison are meted out only for severe crimes (S.O.U. 1972:70). In single-vehicle accidents only 14 of the 54 drivers had a punishment of 25 or less fines. In Sweden a fine is assessed on the basis of the defendant's daily income, and therefore the severity of the crime is indicated by the total number of fines. Most of the drivers had been convicted more than once. Twenty-six drivers were sentenced to prison, eight of them for one year or more. Among drivers involved in multiple-vehicle collisions, 16 were sentenced to 25 or less fines. Only 10 drivers were sentenced to prison, and only one of them to more than one year.

No relationship could be seen in single-vehicle accidents between the type of accident and the driver's age, his criminal tendencies, or his drunken driving.

In this investigation driving while under the influence of alcohol during the accident in question, and/or registration in social and/or criminal records are regarded as proven social deviance. The distribution of these features in the two accident groups is shown in Fig. 6.

In single-vehicle accidents more than 50% of the drivers are shown to be socially deviant.

Twenty-nine drivers had only been driving inebriated, five were only registered in social registers, and six were only registered in criminal records. Thirty-nine drivers were registered in at least 2 of the 3 categories of social deviance.

Twenty-six of the above-mentioned drivers had been driving intoxicated when the actual accident occurred and were also registered in both social and criminal records.

In drivers involved in multiple-vehicle collisions these findings are less marked; only 79 out of the 383 drivers showed signs of social deviance—that is, driving while intoxicated and/or registered in the social and/or criminal registers.

Of the above-mentioned 105 drivers in single-vehicle accidents with proven social deviance,

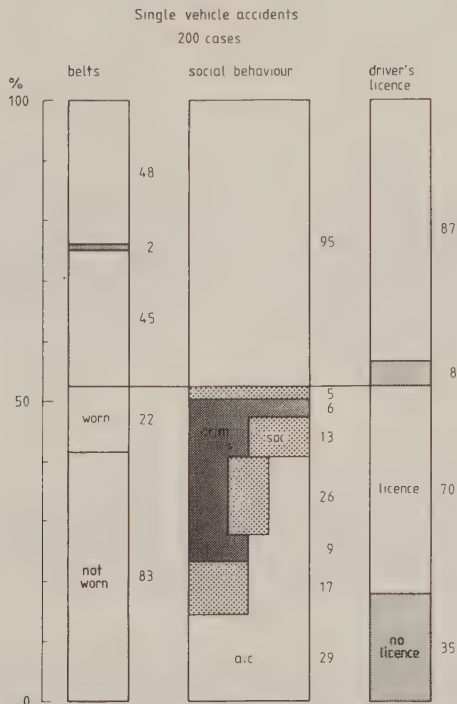


Fig. 6(a)

35 (33%) of them were driving without any license at all. Of the 79 socially deviant drivers in multiple-vehicle collisions, 17 (22%) of them did not possess any license.

The use of safety belts was rather uncommon (26%) among drivers involved in single-vehicle accidents, contrary to drivers in multiple-vehicle accidents, who used safety belts more commonly (69%).

Among drivers that fulfilled the above-mentioned criteria for social deviance, only 21% in single accidents and 46% in collisions between vehicles used safety belts.

DISCUSSION

Investigations dealing with a comparison between single-vehicle accidents and collisions between vehicles are difficult to perform due to problems in gathering material usable for such an investigation. It is not possible to compare all accidents occurring in a well-defined geographic area, as a great number of these accidents, even those with injured participants, are not brought to the attention of the authorities, the insurance companies, or medical personnel. Analyses of accident causation must therefore be limited to selected accident material. The present investigation deals with a nearly complete sample of the most severe accidents, i.e. those resulting in fatalities, occurring during the year 1975 in the whole of Sweden. In this material the victim who survived longest died after 101 days. Accidents of this kind were without exception reported to the authorities and were always thoroughly investigated.

Concerning the point of time during which the accidents took place, it could be confirmed that they tended to occur late in the day and on weekends [Hansson, 1975; Henderson, 1971; Ryan, 1976; S.O.U. 1970:61; Waller, 1969]. However there is a marked difference between single-vehicle accidents and multiple-vehicle collisions: collisions between vehicles took place especially often during the afternoon rush hour, whereas single-vehicle accidents occurred

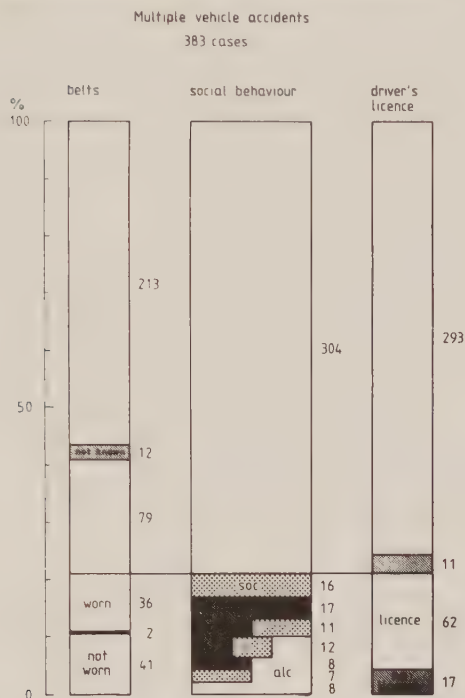


Fig. 6(b).

Fig. 6. (a) Frequency of 200 drivers in single-vehicle accidents and (b) of 383 drivers in multiple-vehicle accidents—with and without criminal (crim) and/or social (soc) records and/or driving intoxicated at the time of the accident (alc). The frequency of belt usage and drivers' possession of a licence in the two groups, single- and multiple-vehicle accidents, is given in the parallel histograms. The height of the histograms refers to the relative number of drivers contained in the different groups and the written number, to the absolute number of drivers. All socially deviant drivers, i.e. belonging to the groups: crim, soc and alc, are gathered together below the horizontal line and diversified into the groups mentioned. Their usage of seat belts and their possession of a drivers licence is also demonstrated. Above the horizontal line the same principle of diversification is used among the socially well-adapted drivers. For example, in single-vehicle accidents 29 drivers drove inebriated only, 17 drove inebriated and were also registered in the Social Register, 9 drove inebriated and were also registered in the Criminal Records and so on. Among these 105 socially deviant drivers involved in single vehicle accidents, 35 had no drivers' licence at all and 83 did not wear safety-belts.

mainly on weekends. According to official statistics there is an increase of 10% in the traffic density on the weekends and a corresponding increase in accident frequency should be expected. However, the number of weekend single-vehicle accidents in the present material exceeded the expected figure. Furthermore, single-vehicle accidents took place more often at night and thus in darkness. According to Satterthwaite [1976] single-vehicle accidents and head-on collisions are especially common in wet weather. Our results show that multiple-vehicle collisions occurred more frequently than single-vehicle accidents during poor weather conditions such as rain, snow, or fog ($p < 0.01$, χ^2 18.22, 4 d.f.).

Thorough investigation undertaken by the police at the site of the accidents show that skidding before impact in single-vehicle accidents is quite common, and this fact may indicate poor control of the vehicle by the driver in these accidents.

There is a difference in the interrelationship between the two types of accidents under study with regard to the road speed limit in force. Single-vehicle accidents occurred more often on roads with a speed limit of 70 km/h (43 mph) and collisions between vehicles on roads with a limit of 90 km/h (56 mph) ($p < 0.05$, χ^2 11.72, 5 d.f.). Single-vehicle accidents also took place more often on roads with a surface consisting of gravel than collisions between vehicles ($p < 0.001$, χ^2 31.06, 4 d.f.).

Compared with the ages of drivers' licenses possessors in the country the young drivers are overrepresented in our material on fatal accidents. This is a well-known fact [Dureman, 1972]. Different explanations have been proposed. For example, longer driving distance per year should slightly increase the accident risk [Dureman, 1972]. However, it is doubtful whether the young motorists drive more kilometers per year than do their older counterparts. Regardless of the number of kilometers, the younger motorists drive per year, they are more inexperienced, a fact which is surely of importance. There is also a strong suspicion [Dureman, 1972; Henderson, 1971] that higher accident rate may be due to the different attitudes and personality of young drivers. The fact that in our material there is a marked age difference between drivers involved in single-vehicle accidents (mean age 34, median age 29) compared to drivers involved in collisions between vehicles (mean age 42, median age 38) gives some support to this opinion. According to Henderson [1971] and S.O.U. [1970:61] elderly drivers are especially accident-prone on those occasions demanding a high degree of attention. In the present material elderly drivers were very seldom involved in single-vehicle accidents but somewhat more often involved in collisions between vehicles. Especially in crossing collisions and in turning collisions, elderly drivers are markedly overrepresented, possibly due to their increased lack of perception [Henderson, 1971]. Similar to the results of other investigations [Dalgaard, 1977; Tolagen, 1977] the number of female drivers in the present material is very small.

Driving while under the influence of alcohol is well-known as a major factor in the causation of traffic accidents [Haddon, 1959; Hansson, 1975; Lindgren, 1974; Ryan, 1976; S.O.U. 1970:61; Tonge, 1977; van den Oever, 1976; Waller, 1969; Vaughan, 1975].

Surviving drivers subjected to blood alcohol investigation in the present material were selected by the police, because the drivers were suspected of drunken driving. Thus, no conclusions concerning the frequency of drunkenness among the surviving drivers can be drawn. Concerning fatally injured drivers, only those cases who survived the accident more than 8 hr were excluded from chemical analyses. Thus, 88% of the fatally injured drivers in single-vehicle accidents and 78% of the fatally injured drivers in multiple-vehicle collisions were tested for blood alcohol. Among these victims 50% of the fatally injured drivers in single-vehicle accidents and 12% of those in collisions between vehicles had a blood alcohol concentration exceeding 0.05%. The difference of the relative number of inebriated fatally injured drivers between the two types of accidents is statistically significant ($p < 0.001$, χ^2 166.72, 1 d.f.).

The results among the fatally injured drivers probably give a reliable picture of the number of drivers under alcoholic influence and the degree of inebriation in severe automobile accidents. The highly differing results between the two groups, surviving and fatally injured drivers, show the very low validity of reports concerning alcohol concentration in drivers surviving severe automobile accidents. There is no difference in the degree of inebriation between the drunken drivers in single-vehicle and multiple-vehicle accidents. As noticed by Hansson [1975], S.O.U. [1970:61] and Tonge [1977] drunken driving is most frequent among drivers 20–30 yr of age, and not in the youngest drivers. Considering this information and the fact that more than half of the inebriated drivers exceeded an alcohol concentration of 0.15%, Waller's [1969] suspicion that many of these drivers are chronic alcoholics may be supported.

Driving inebriated and chronic alcoholism are in Sweden regarded as signs of social deviance. It is well-known that drunken drivers as well as drivers involved in traffic accidents often suffer from a heavy social and criminal burden [Berglund, 1974; Dureman, 1972; Kraus, 1970; Robertson, 1975; S.O.U. 1972:70; Suchman, 1970; Tillman, 1949]. If registration in both criminal and social records and drunken driving in the accident in question are regarded as signs of social deviance, such a deviance was found among more than 50% of the drivers involved in single-vehicle accidents, as opposed to only 20% of the drivers involved in collisions between vehicles. This difference is statistically significant in itself ($p < 0.001$, χ^2 124.16, 1 d.f.). However, regarding drivers involved in single- or multiple-vehicle accidents, one must take into account that there are twice as many drivers per accident involved in multiple-vehicle collisions. If one compares the frequency of certain uncommon personal characteristics, which are of possible importance in the causing of collisions, of the two groups of drivers, the difference would be too big.

In order to judge whether there is a real difference, one might imagine a distribution of these

characteristics showing—in theory—the least difference between the drivers in the two types of accidents. In this case we presuppose that only one driver in each collision between vehicles caused the accident and furthermore that all socially deviant drivers were among these. After this we compare the relative number of socially deviant drivers causing the accidents, i.e. all drivers in single-vehicle accidents and half the number of drivers in multiple-vehicle collisions, where under these provisions about 40% of the latter should be socially deviant. In spite of this estimation, the difference in the proportion of socially deviant drivers in collisions and single-vehicle accidents remains statistically significant ($p < 0.01$, $\chi^2 10.64$, 1 d.f.).

The degree of social deviance of the different drivers in question varied somewhat according to our definition. Some of the drivers fulfill all three criteria and others only one of them. Exhibiting two or more of these mentioned signs of social deviance is considered as well-established social deviance, and is shown by 62% of all socially deviant drivers in single-vehicle accidents and 48% of all these drivers in collisions between vehicles ($p < 0.01$, $\chi^2 8.02$, 1 d.f.). Furthermore, double registration within the criminal record and the social record (Figs. 4 and 5) is much more common among the socially deviant drivers in single-vehicle accidents, than those involved in multiple-vehicle accidents.

Possession of a driver's license and the use of seat belts is not so common among the drivers with high social deviance as compared to socially well-adapted drivers, but is more common in those socially deviant drivers participating in collisions between vehicles than among those drivers participating in single-vehicle accidents. (Statistical difference between the two groups: socially deviant drivers in multiple- and single-vehicle accidents concerning the use of seat belts $p < 0.001$, $\chi^2 31.24$, 2 d.f. and concerning possession of a driver's license $p < 0.01$, $\chi^2 8.69$, 1 d.f.).

The results of this investigation show that drivers in single-vehicle accidents differ from drivers in multiple-vehicle collisions regarding both age and social behaviour, including such factors as possession of a driver's license and the use of seat belts. Furthermore, there are obvious differences in such external factors as type of accident, time of day and week, weather conditions, road surface, and the speed limit in force.

It has been suspected that single-vehicle accidents might be camouflaged suicides. If so, contrary to other suicides, these took place with total lack of the usually occurring hints concerning suicide intentions. In our material there is only one single-vehicle accident driver who left a message to his relatives, thereby unveiling the true nature of the accident. The very seldomly occurring hints of suicidal intentions may of course be explained by the fact that family members do not want to make their suspicions known to the police, for insurance or other reasons.

The findings of this investigation, especially concerning the drivers in single-vehicle accidents, indicate that many of these drivers show socially deviant personality traits, and some of them might be persons with different types of psychopathic states as defined by Cleckley: "They are frequently callous and hedonistic, showing marked emotional immaturity, with lack of sense of responsibility, lack of judgement, and an ability to rationalize their behaviour so that it appears warranted, reasonable, and justified".

If so, approaches to prevent these severe accidents should take into account, among other things, the above-mentioned differences between types of accidents and drivers, including socially deviant personality traits.

REFERENCES

- Berglund E., Rattfyllerister, Alkoholproblem, Återfall, Kriminalitet m m. Beteendevetenskapliga institutionsgruppen. Kriminalvårdsstyrelsens rapport nr 8, 1974.
- Cleckley H. M., Psychopathic states. *American Handbook of Psychiatry* 1, 568–588, 1959.
- Dalgaard J. B., Experiences with new seat belt law. *Proc. 6th. Int. Conf. of IAATM, Australia*, p. 56–69, 1977.
- Dureman I., Prediktion, diagnos och rehabilitering inom trafiksäkerhetsarbetet. Statens Offentliga Utredningar (S.O.U.) (Stockholm) 72, 1972.
- Haddon W. Jr., *Alcohol in the Single Vehicle Fatal Accident*. *JAMA* 169, 127–133, 1959.
- Hansson C., Alcohol and single vehicle fatal accidents in southern Sweden 1972–1973. To be published.
- Henderson M., Human factors in traffic safety. *A reappraisal*. *Traffic Accident Research Unit, Australia*, 1, 1971.
- Kraus A. S. et al., Pre-driving identification of young drivers with a high risk of accidents. *J. Safety Research* 2, 55–66, 1970.
- Lindgren Å., Motor claims of abstaining drivers. *6th Int. Conf. on Alcohol, Drugs and Traffic Safety, Toronto*, 1974.

- van den Oever R., Alcohol en verkeer Officiële detectie van het rijden onder invloed, de top van de ijsberg. *Arch. Belg. Med. Soc.* 34, 79-86, 1976.
- Robertson, L. S., Prior violation records of 1447 drivers involved in fatal crashes. *Accid. Anal. & Prev.* 7, 121-128, 1975.
- Ryan G. A. *et al.*, Blood alcohol and road trauma survey. *Med. J. Aust* 63, 129-131, 1976.
- Satterthwaite S. P., An assessment of seasonal and weather effects on the frequency of road accidents in California. *Accid. Anal. and Prev.* 8, 87-96, 1976.
- Statens Offentliga Utredningar (S.O.U.): Trafiknykterhetsbrott. (Stockholm), 61, 1970.
- Statens Offentliga Utredningar (S.O.U.): Rätten till ratten. (Stockholm), 70, 1972.
- Suchman E. A., Accidents and social deviance. *J. Health Soc. Behav.* 11, 4-15, 1970.
- Tillman W. A., The accident-prone automobile driver. A study of the psychiatric and social background. *Am. J. Psychiatry.* Nov., 321-331, (1949).
- Tolagen A., Trafikskadade i Östergötland. En undersökning av skadade i trafiken i Östergötlands län under 1.5 års tid. Supp. 43, *Opusc. med.* (Stockholm), 1977.
- Tonge J. I. *et al.*, Traffic-crash fatalities (1968-1973): Injury patterns and other factors. *Med. Sci. Law* 17, 9-24, 1977.
- Vaughan R. G., The epidemiology of pole crashes. *Traffic Accident Research Unit, Australia*, 3, 1975.
- Waller J. A. *et al.*, Alcohol and other factors in California highway fatalities. *J. Forensic Sci.* 14, 429-444, 1969.

OCCURRENCE OF BARBITURATE, BENZODIAZEPINE, MEPROBAMATE, METHAQUALONE AND PHENOTHIAZINE IN CAR OCCUPANTS KILLED IN TRAFFIC ACCIDENTS IN THE SOUTH OF SWEDEN

PETER KRANTZ and OLOF WANNERBERG

Department of Forensic Medicine, University of Lund (Sweden)

(Received March 24, 1980; in revised form November 2, 1980; final revision accepted May 13, 1981)

Summary

An investigation of the following psychoactive drugs: barbiturate, benzodiazepine, meprobamate, methaqualone and phenothiazine, was performed on all automobile occupants killed in accidents in southern Sweden during 1977 and 1978. Of 122 drivers and 55 passengers analysed, low concentrations of these drugs were found in nine drivers and in five passengers. Thus, 7.3% of the drivers were driving under the influence of drugs and, of these, two drivers (1.6% of all analysed drivers) were also inebriated. Twenty-three per cent of the drivers were inebriated only. According to the circumstances in the accidents and the number of drivers whose analyses proved positive, drug influence seldom seems to be the cause of fatal traffic accidents.

Introduction

Driving under the influence of alcohol is generally regarded as one of the most important causes of traffic accidents. Consequently, drunken driving is against the law in most countries. Stipulation of the degree of inebriation is technically simplified by the fact that alcohol is a quantitatively and qualitatively easily analysed substance. The penalty can be based on the blood alcohol concentration. Little is known about psychoactive drugs taken by motor vehicle drivers with regard to the cause of traffic accidents, because information is incomplete concerning both the frequency of drugged drivers and the potential risk of driving under the influence of these drugs.

About 50% of drivers involved in fatal single accidents are found to be driving under the influence of alcohol. In contrast, only a few drivers per 1000 routinely controlled persons are inebriated. Thus, there is a large overrepresentation of inebriated drivers involved in accidents, indicating the great danger of driving inebriated. If psychoactive drugs are of importance as a cause of traffic accidents, an accumulation of persons driving under the influence of drugs should be expected in accidents resulting in fatalities. At the Department of Forensic Medicine in Lund all persons killed in traffic accidents in southern Sweden are autopsied. This offers an opportunity to investigate a complete group regarding the occurrence of such psychoactive drugs. In Sweden, as well as in many other countries, the most commonly used tranquilizers are barbi-

turate, benzodiazepine, meprobamate, methaqualone and phenothiazine. Of course, there are other drugs which can impair driving ability but the above-mentioned substances are reported to be the ones which, in practice, are the most important in this regard [1].

Methods

If possible, blood, urine, stomach content and liver tissue were preserved for analyses at our chemical laboratory. Samples were also, because of legal reasons, analysed for alcohol by gas chromatography at the Government Laboratory for Forensic Chemistry in Stockholm (GLFC).

For analyses of the possible presence of the drugs barbiturate, meprobamate, methaqualone and phenothiazine, liver tissue was used. The extraction was similar for these substances though the methods of analysis differ. Urine and blood were used for benzodiazepine analysis. The methods applied for quantitative and qualitative analyses of each substance are described below.

Barbiturate

The basic method is described by Bonnicksen *et al.* [2] and modified as follows: 20 g liver and 80 g of 70% alcohol were treated in a blender and centrifuged after standing in a refrigerator for 12 h. Twenty-five grams of the supernatant were evaporated to a volume of 5 ml. Twenty ml of 0.01 M hydrochloric acid were added and the mixture was heated to 70 °C and afterwards refrigerated to 0 °C. After filtration this procedure was repeated. The filtrates were shaken vigorously for 1.5 minutes in a separatory funnel with three portions, each of 50 ml of chloroform. All chloroform solutions were combined and evaporated to 5 ml. For spectrophotometric analyses 1 ml of the chloroform solution and 4 ml of 0.5 M ammonia were shaken for 1 minute and centrifuged. The ammonia phase was read at the wavelength 225 - 300 nm. If the spectrum showed the maxima typical for barbiturates, 0.3 ml of 6 M hydrochloric acid was added to the ammonia solution and the absorbancies for the same wavelength were re-read. The difference gives a measure of the total barbiturate content.

Benzodiazepine

Urine and/or blood were analysed qualitatively according to the method described by Bonnicksen *et al.* [3] modified as follows: the specimen was treated with concentrated hydrochloric acid and after hydrolysis brought to pH 11. Extraction was made by ether. The solution was evaporated and alcohol was added. Seventy μ l of the alcohol solution were chromatographed on a thin-layer plate coated with silica gel 60. The plate was chromatographed with benzene-acetone, 95:5. The spots were developed with sodium nitrite and β -naphthol. Diazepam, Klopoxid (chlordiazepoxide) and Nitrazepam were used as reference substances. Their hydrolysates correspond to all benzodiazepines and their metabolites registered in Sweden during the period under study.

For quantitative analysis gas chromatography with a 3% OV 17 column coated with chromosorb W-HP80-100 was used. The limit for detection was 0.03 mg%, 0.04 mg% and 0.1 mg% for the above-mentioned hydrolysates respectively. This is about the blood concentration for therapeutic use, but the thin-layer chromatography is more sensitive, and therefore used for screening.

Meprobamate

The methods for extraction and thin-layer chromatography were described by Bonnichsen and Holmgren [4] and Bonnichsen *et al.* [2]. Thus, extraction from liver tissue was done in the same way as for barbiturate analysis. The chloroform solution was evaporated (after separation with ammonia), dissolved with alcohol and chromatographed with methanol and chloroform (1:9) on a thin-layer plate coated with silica gel 60. The plates were developed with furfural and ether and afterwards with concentrated hydrochloric acid.

Quantitative analysis was made colorimetrically according to the method described by Madsen [5]. The limit for detection is about 0.1 mg%.

Methaqualone

The liver tissue was routinely extracted according to the method described for meprobamate. One ml of the ammonium treated chloroform solution was evaporated and 3.0 ml of 75% alcohol were added. Spectrophotometric analysis was done at 290 - 350 nm. The limit for detection is about 0.1 mg%. The specimens were also analysed by gas chromatography in the same way as for benzodiazepines. The limit for detection is also about 0.1 mg%.

Phenothiazine

The method used was described by Bonnichsen *et al.* [2] modified as follows: before the procedure described by Bonnichsen the blended liver tissue was extracted by alcohol overnight. Both spectrophotometric and thin-layer chromatography analyses were carried out. The limit for detection is about 0.2 mg%.

Results

In 1977 and 1978 a total of 403 persons killed in traffic accidents in southern Sweden were autopsied. Two hundred and twenty-two were occupants of automobiles and, out of the 145 automobile drivers who died, 23 were not analysed on account of survival time exceeding 10 hours or because of extensive treatment including blood transfusion. Among the 77 passengers, 22 were not analysed for the same reasons, or because they were under 15 years of age (nine passengers).

Eighty-five of the 122 drivers and 35 of the 55 passengers were not under the influence of alcohol or drugs. Twenty-eight drivers and 15 passengers were inebriated only. Barbiturate or phenothiazine was not found in any occupant. Meprobamate was found in two drivers and one passenger. In these

three it was found in a concentration of 0.1 mg% in the kidney of one, in trace amounts in the liver of the second and in trace amounts in the stomach contents of the third. Traces of methaqualone were found in two drivers and in one passenger and traces of benzodiazepine in four drivers and in three passengers, i.e. concentrations below the above-mentioned quantitative detection limits. Low concentrations of methaqualone in liver and benzodiazepine in urine were found in one driver.

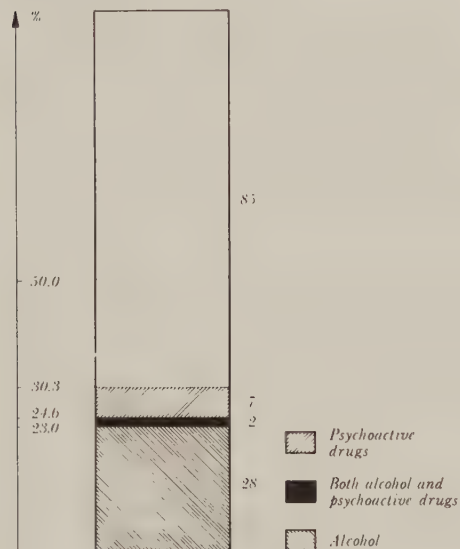


Fig. 1. Drugs and alcohol found in 122 drivers analysed.

Thus, 9 drivers out of 122 (7.3%) had detectable concentrations of the drugs for which analysis was done (see Fig. 1). The corresponding figures for passengers were 5 out of 55 (9.1%).

Regarding the possible influence of these drugs on the cause of the accidents it can be stated that four drivers were guiltless of the accident because they were hit on their own side of the road, etc. None of them was driving under the influence of alcohol.

Two drivers were driving under heavy influence of alcohol (about 0.3% in blood) and in these drivers methaqualone was found in one and benzodiazepine in the second. In these cases the degree of inebriation makes it likely that they would have met with these accidents whether they had taken the drugs or not.

In the remaining three cases it is possible that the influence of the drugs was of some importance in the cause of the accidents. They are therefore detailed in the following case reports.

Case 1

A driver, 25 years of age, drove off a highway to the left into the ditch and rolled over. He was alone in the car and thrown out of it. He was possibly a marijuana smoker as a pipe for this purpose was found in the car. At the analyses, methaqualone and benzodiazepine were found in the above-mentioned concentrations.

Case 2

A driver, 34 years of age, was driving in heavy traffic on a highway when he suddenly deviated too much to the left from the right side of the road and collided with an oncoming truck. He was not inebriated but traces of benzodiazepine were found in blood and urine. There is no explanation for the cause of the accident. It is possible that he fell asleep, perhaps due to the influence of the benzodiazepine.

Case 3

A driver, 66 years of age, failed to stop at a crossing where he should have done so. Instead he drove straight out and was hit from the left. Alcohol was not found, but traces of benzodiazepine were in urine and blood. This kind of accident is not unusual among elderly drivers [6], but it is possible that the influence of the anxiolytic drug decreased his perceptive abilities. Apart from the driver a passenger in the rear seat was also killed.

Concerning the five passengers, none was inebriated and benzodiazepine was found in three cases, methaqualone in one case and meprobamate in another case. The drugs were only found in low concentrations. Information concerning the accidents does not point to their having any part in the cause of these accidents, for example by interfering with the driving of the car.

Discussion

Despite the fact that some psychotropic drugs are known to decrease driving ability it is, according to many investigators [1, 7 - 9], doubtful whether these drugs are important as a contributing factor in traffic accidents. Different ways of investigation have been proposed.

Knowledge about specific drugs and the influence they have on driving ability is not complete. According to Sharma [10] barbiturate decreases driving ability and the effect is reinforced by alcohol. Benzodiazepines alone have very little effect on driving ability, but combined with alcohol a decrease of reaction time, etc. is observed [11, 12]. Concerning such psychotropic drugs as meprobamate, methaqualone and phenothiazine there is, according to Colburn *et al.* [13], some laboratory evidence for a dose-related decrease of certain intellectual and perceptual functions.

Knowledge about drug use in different groups of non-accident traffic participants for comparison with drivers involved in traffic accidents would be interesting, but valid control material is unfortunately, for obvious reasons,

not available. For example, 5% of the inhabitants in Sweden regularly use anti-anxiety sedative drugs for one month or more each year according to Balter *et al.* [14]. This finding is of minor value for estimation of the accident risk when driving under the influence of drugs. Among people involved in traffic accidents an accumulation of those using these drugs would be expected if the drugs were an important cause of these accidents, as is the case with alcohol.

In four different investigations [15 - 18] it has been shown that in approximately 10% of the drivers involved in accidents some sort of drugs were detected, and in another 10% both drugs and alcohol. These investigations were all performed in the U.S.A. In other investigations (e.g., ref. 19), a higher percentage of drivers involved in accidents had positive drug analyses but in these cases the drivers were selected because they were suspected of driving inebriated.

In the present investigation performed on all car occupants killed in traffic accidents in a certain area of Sweden over two years, psychoactive drugs were only found among 7.3% of the drivers. Only two drivers were shown to be driving both inebriated and under the influence of drugs. It is possible that drugs were of importance as a cause of accident in only three of the 122 investigated drivers, though in one of these three the suspicion is rather vague. The difference in our results and those in studies from the U.S.A. might be explained by differences in driving and medical habits in the two countries.

This investigation suggests that drug use is probably at present a minor factor among the causes of traffic accidents. Systematic postmortem analyses on victims of fatal automobile accidents will be needed to follow new trends.

References

- 1 J. A. Waller, Drugs and highway crashes. *J. Am. Med. Assoc.*, 215 (1971) 1477.
- 2 R. Bonnichsen, A. C. Maehly and A. Frank, Barbiturate analysis: Method and statistical survey. *J. Forensic Sci.*, 6 (1961) 411.
- 3 R. Bonnichsen, A. C. Maehly and S. Åqvist, Arzneimittel und Fahrtüchtigkeit. *Blutalkohol*, 7 (1970) 1.
- 4 R. Bonnichsen and P. Holmgren, A report on autopsy cases involving hexapropylmethylxanthine. *Zacchia*, 10 (1974) 1.
- 5 O. D. Madsen, Colorimetric determination of meprobamate in blood. *Clin. Chim. Acta*, 7 (1962) 481.
- 6 P. Krantz, Differences between single - and multiple - automobile fatal accidents. *Accid. Anal. Prev.*, 11 (1979) 225.
- 7 J. D. J. Havard, Drugs and driving. *Br. J. Hosp. Med.*, 4 (1970) 455.
- 8 E. Kibrick and R. G. Smart, Psychotropic drug use and driving risk: a review and analysis. *J. Safety Res.*, 2 (1970) 73.
- 9 R. G. Smart, W. Schmidt and K. Bateman, Psychoactive drugs and traffic accidents. *J. Safety Res.*, 1 (1969) 67.
- 10 S. Sharma, Barbiturates and driving. *Accid. Anal. Prev.*, 8 (1976) 27.
- 11 P. Kielholtz, L. Golberg, J. Im Obersteg, W. Poeldinger, A. Ramseyer and P. Schmid, Strassenverkehr, Tranquilizer und Alkohol. *Dtsch. Med. Wochenschr.*, 92 (1967) 1525.
- 12 N. C. Moore, Medazepam and the driving ability of anxious patients. *Psychopharmacol.*, 52 (1977) 103.

- 13 H. N. Colburn and B. H. Garland, Drug (other than alcohol) and driving. *Proc. of the Scientific Conference on Traffic Safety*, Ottawa, 1974.
- 14 M. B. Balter, J. Levine, D. I. Manheiner, Cross-national study of the extent of anti-anxiety-sedative drug use. *N. Engl. J. Med.*, 290 (1974) 769.
- 15 J. H. Davis, Carbon monoxide, alcohol, and drugs in fatal automobile accidents, Dade county, Florida, 1956 - 1968. *Clin. Toxicol.*, 7 (1974) 597.
- 16 J. C. Garriott, V. J. M. DiMaio, R. E. Zumwalt and C. S. Petty, Incidence of drugs and alcohol in fatally injured motor vehicle drivers. *J. Forensic Sci.*, 22 (1977) 383.
- 17 R. F. Turk, A. J. McBay and P. Hudson, Drug involvement in automobile driver and pedestrian fatalities. *J. Forensic Sci.*, 19 (1974) 90.
- 18 E. J. Woodhouse, The incidence of drugs in fatally injured drivers. *Fifth International Conference of the International Association for Accident and Traffic Medicine*, September 1975.
- 19 B. S. Finkle, Drugs in drinking drivers: A study of 2,500 cases. *J. Safety Res.*, 1 (1969) 179.

INJURY RESPONSE IN BELTED AND UNBELTED CAR OCCUPANTS RELATED TO THE CAR CRASH ENERGY IN 458 ACCIDENTS

A study of all fatal automobile accidents in Sweden 1975

by

Peter Krantz and Peter Löwenhielm
Department of Forensic Medicine
University of Lund
Sweden

Introduction

Injuries to automobile crash victims are common and costly to society. In order to reduce the severeness of the injuries and to save lives, seat belt use has been legislated in many countries. The effectiveness of the seat belts in reducing injuries to car occupants has been shown by many investigators (1,2,3,4). The protective effects of seat belts are undoubtedly dependent on such factors as the type of accident, the type of car, the age of the car occupant etc. Studies on injury patterns in those immediately killed are important for further improvement of safety measures. In order to get a conception if the number of fatal casualties can be reduced by improved emergency medical care, studies of those cases who survive for some time is necessary.

The choice of the crash injury sample for such a study is of crucial importance. Contrary to other investigations, this investigation has been based on a one year selection of all fatal automobile accidents in a country with high medical standards.

Material and Methods

In all 458 automobile accidents with fatal outcome occurred in Sweden 1975. In these accidents 1366 persons were involved, 560 of which were killed. A person who survives the accident but dies within 1 year is considered killed. In the present investigation the killed car occupants as well as the surviving occupants are included. In all of these cases, data have been collected from police reports, autopsy records, case sheets, photographs from the scene of accident and the damaged cars, and from day-to-day reports supplied by the Swedish Road Traffic Safety Authority. Only 14 persons killed in automobile traffic accidents this year were not subjected to autopsy and the cause of death in these cases have been taken from the death certificates.

Since 1975 seat belt use is mandatory in Sweden for front seat occupants. The seat belt use by the back seat passengers is quite low, and in order to get test groups of comparable sizes only the front seat occupants, i.e. the drivers and the front seat passengers have been included in the evaluation of the injury reducing effectiveness of the seat belts.

In the analysis some cases have been excluded: occupants in cars underdriving lorries have not been studied more closely and persons thrown out of the car have been analysed as a special group.

The body injuries have been registered as to the type (eg. aortic rupture, lung contusion etc.), the location (eg. head, neck, thorax, abdomen, pelvis and extremities) and the severity. In evaluating the severity the Abbreviated Injury Scale (AIS 1976 revision) has been used. The AIS range from 0 to 6, where 0 indicates no injury and 6 fatal untreatable lesions.

When for a given person, the overall injury has been evaluated the Injury Severity Scale (ISS) proposed by Baker et al (5) has been applied. The ISS is the sum of the squares of the highest AIS codes in each of the three most severely injured body regions. The persons studied may have additional lesser injuries to other body regions but these are not considered in determining the ISS. In her work Baker recommended that injuries scoring 6 according to AIS should be omitted or valued 5 since they were not considered to be frequent. In the present material maximal AIS rating is at hand in a considerable number of cases and therefore the calculation of the ISS has been based on the original AIS score.

In order to get a comprehension of the impact energy, the accidents were studied as to the deformation of different zones of the car (cf. fig. 1). The car was subdivided into 8 zones. In addition the degree of intrusion of the steering wheel and the deformation of the dashboard was recorded, and these interior parts of the car were included as separate deformation zones.

The deformation (D) of each zone was scored from 0 to 3, where 0 indicates no deformation and 3 a fully deformed zone. In order to get an estimate of the impact energy (IE) for the different cars involved the deformation score was squared and summed up for all deformation zones:

$$IE = D(1)^2 + D(2)^2 + \dots + D(10)^2$$

The value of IE then reflects the impact energy and should offer a qualitative tool for the selection of comparable accidents.

In order to determine actual differences in the present material statistical methods were employed. In the tests for significance the parameters studied were assumed to be normal with an average and a standard deviation or with a frequency. A two-tail test was always performed.

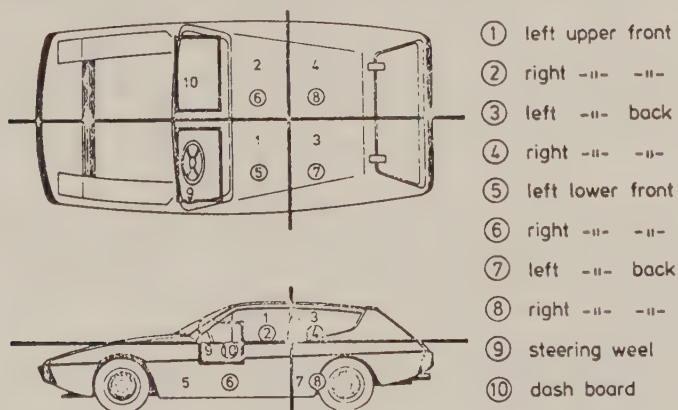


Fig 1. Definition of the deformation zones. 5-8 include hood and trunk.

ISS distribution in surviving and killed front seat occupants

figg. 2 and 3 presents the distribution of the ISS in surviving and killed drivers and front seat passengers. According to fig. 3 there are some occupants with quite low ISS. Some of the deceased died from posttraumatic complications such as pneumonia and pulmonal fat or thrombo embolism. Four persons died from drowning in cars submersed in water. In 14 cases no autopsy was performed and in these cases an estimate of the ISS was made from the death certificates from which it is impossible to obtain a complete AIS scoring.

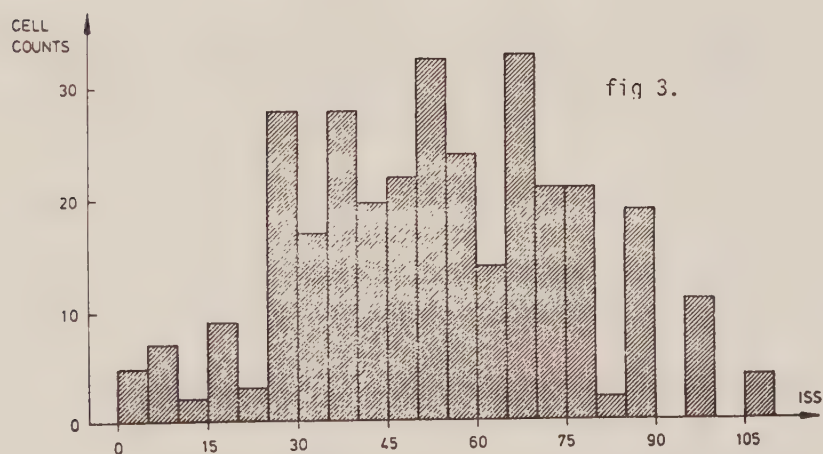
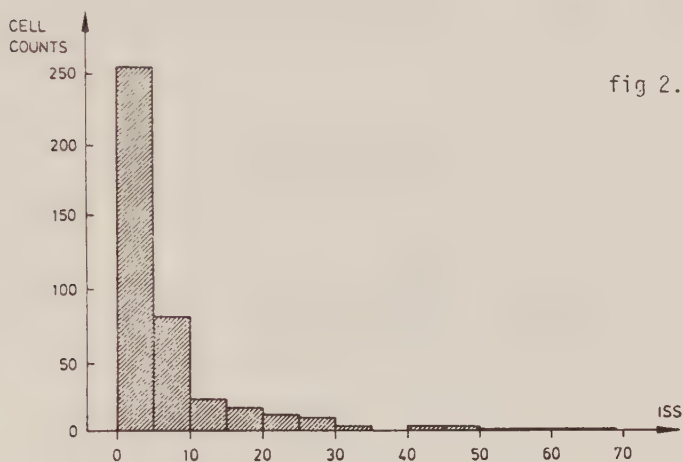


fig 2 and 3. ISS distribution in surviving (2) and killed (3) occupants

An attempt to define a critical ISS level has been made such that there are as many deceased persons with an ISS value below this level as there are surviving with an ISS value exceeding this critical level. The so calculated critical level is ISS=25 and it corresponds to an AIS=5 value in one body region or to AIS=3 and AIS=2 for two body regions respectively.

A rough estimate to correlate this injury level to a relative collision speed of the vehicle has been made. Langwieder (6) has presented an injury material comprising 29.000 accidents: the severity of the injuries suffered by the deceased occupants in frontal collisions has been correlated to an equivalent test speed. Furthermore a corrective factor for the equivalent test speed in relation to the relative collision speed, i.e. the real speed at the moment of impact, is presented. The data presented by Langwieder are compared to the present material and calculations yield a relative collision speed of about 45 km/h corresponding to the above mentioned critical ISS level.

Type and frequency of the injuries suffered by belted and unbelted car occupants

The most frequent injuries suffered by belted and unbelted car occupants are listed in table 1, which also accounts for some injuries which differ in frequency in the belted and unbelted group.

Blunt trauma to the head with skull fractures and brain lesions is well known as frequent in traffic casualties. In the present material there is a *** significant difference regarding the cortical contusions and a ** significant

Type of injury	Frequency		Significance level
	belted %	unbelted %	
Lung contusion	16.5	27.7	***
6-10 rib fractures	23.1	26.3	-
1- 5 rib fractures	21.3	23.6	-
Liver rupture	11.5	18.1	**
Pelvic fracture	16.5	18.5	-
Femur fracture	14.1	17.2	-
Face injuries(§)	14.5	17.1	-
Brain cortical contusion	9.0	16.2	***
Lung laceration	9.9	15.5	**
Commotio cerebri(§)	10.5	13.7	*
Spleen rupture	7.8	13.3	**
Cross fracture of the base of the skull	7.6	13.1	**
Impression fracture of the base of the skull	7.0	12.1	**
Aortic istmus rupture	7.8	11.0	**
Heart laceration	7.8	10.0	-
Disruption of many bridging veins	4.2	8.2	**
Fracture of iliac crest	2.6	0.9	*
Malleolar fracture	5.4	2.8	*

Table 1. Frequently occurring injuries in surviving and killed belted (N=503) and unbelted (N=565) car occupants. (§) indicate surviving occupants only.

difference for various skull fractures, brain laceration, tentorial herniation and disruption of many bridging veins as can be seen in table 1.

Concerning neck injuries significant * difference is found for total disconnection of the occiput from the atlas, as well as cervical spine fractures including fractures of the odontoid process of the axis. Belted drivers tend to suffer from soft tissue injuries to the neck such as injuries to the carotids and the trachea more often than the unbelted do and this difference is evidently caused by the steering wheel.

In agreement with general experience injuries to the thorax with rib fractures and contusions and lacerations to the lungs is a very common finding. Although the number of rib fractures does not differ significantly between the belted and the unbelted group, there is a *** significant difference concerning the lung contusions and on the ** level concerning the lung lacerations.

Among other thorax injuries there is a significant difference ** found regarding rupture of the aorta at the isthmus as well as in the ascending part just above the heart. These aortic ruptures are in many cases attributed to the shovel effect as suggested by Voigt (7).

Ruptures of the liver and the spleen occur more frequently in the unbelted group. There is a ** significant difference and it should be emphasized that rupture of the liver, often with intraabdominal bleeding, is seen in as much as 18 % of the unbelted. Concerning the drivers, the steering wheel was the causative agent in head-on collisions. The front seat passenger suffers from liver rupture in right side collisions.

Fractures of the pelvic girdle occur in comparably high frequency in the belted and unbelted group. However, although not very common, there is a higher incidence of fractures to the iliac crest in the belted group. The difference is significant on the * level and can be attributed to the lap belt.

Concerning injuries to the extremities, i.e. mainly different fractures, there is, apart from fracture of the femur, a slight overrepresentation in the belted group. A reasonable explanation for this difference is a pendulum effect which causes the freely movable extremities to move forward and hit the interior of the car while the trunk is restrained by the seat belts during the crash.

Injury pattern and causes of death in delayed fatalities

Out of the 560 fatalities in the accidents, 156 (28%) survived a varying amount of time. Of these, 20 cases (4% of all) died during the first hour and 52 cases (9% of all) within 3 hours. Seventy-eight cases (14% of all) were deceased within 24 hours and 114 cases (20% of all) within a week.

Forensic autopsy reports and hospital records offered a possibility to carefully penetrate the causes of death in these delayed 156 fatalities. In 67 cases (12% of all) the main cause of death were lacerations and contusions of the brain or brain stem and/or multiple disruptions of the parasagittal bridging veins. Many of these cases had no cerebral function at the arrival to the hospital. Lacerations of the heart or of large vessels accounted for 15 (3% of all) of the casualties. A delayed bursting of an incomplete rupture of the aorta was often

seen in these cases. Multiple rib fractures with flail chest and/or contusions or lacerations of the lungs and diaphragm were seen in 23 cases (2% of all). Because of the severe pulmonary injuries in many of these cases, it was impossible to maintain the lung function despite the fact that they survived for some time and were given intensive medical care. Rupture of the liver, spleen or the gut was regarded as the cause of death in 13 cases (2% of all). Most of these had a total or incomplete laceration of the liver. Six cases (1% of all) were elderly with moderate injuries. Complications due to such moderate injuries, e.g. pneumonia or pulmonary embolism, were the main causes of death in 19 cases (3% of all). Nine cases (2% of all) developed a fat or microthrombotic syndrome. Misdiagnosed epidural haemorrhage, isolated injuries to the extremities, pure aspiration and burn injuries did only account for one case each in this sample.

It is obvious that 72 % of all cases killed in the present material were beyond all medical care as they were immediately killed at the scene of the accident. To judge whether an improved accident medical care might have reduced the number of delayed fatalities is of course very difficult. However, a considerable reduction seems doubtful.

Category	Body region	AIS-rating								Total	ΣAIS^3
		0	1	2	3	4	5	6	N		
unbelted front seat passenger	I	44	3	25	5	5	7	14	103	44.24	
	II	94	0	0	0	7	1	1	103	7.66	
	III	52	0	5	15	5	11	15	103	52.23	
	IV	68	0	0	2	12	20	1	103	34.35	
	V	86	0	1	16	0	0	0	103	4.27	
	VI	67	0	35	1	0	0	0	103	2.98	
belted front seat passenger	I	87	3	24	4	5	7	16	146	33.93	
	II	134	0	0	0	9	1	2	146	7.76	
	III	78	0	16	21	8	10	13	146	36.06	
	IV	112	0	2	4	13	15	0	146	19.39	
	V	123	0	2	21	0	0	0	146	3.99	
	VI	99	1	44	1	1	0	0	146	3.04	
unbelted driver	I	90	5	23	12	6	16	29	185	49.63	
	II	176	0	0	0	9	0	0	185	3.11	
	III	89	0	9	17	12	19	39	185	65.39	
	IV	121	0	1	1	26	33	3	185	34.98	
	V	158	0	0	27	0	0	0	185	3.94	
	VI	111	0	72	2	0	0	0	185	3.40	
belted driver	I	144	17	56	5	6	28	41	297	44.92	
	II	276	0	0	0	18	0	3	297	6.06	
	III	156	0	31	35	15	28	32	297	42.30	
	IV	222	0	4	7	31	33	0	297	21.31	
	V	249	0	2	46	0	0	0	297	4.23	
	VI	187	1	106	2	1	0	0	297	3.26	

Table 2. AIS classified injuries for each body segment in front seat occupants. I: head, II: neck, III: thorax, IV: abdomen, V: pelvis, VI: extremities.

AIS rating of body injuries in drivers and front seat passengers

In order to get a comprehension of the injuries classified according to AIS, table 2 illustrates the highest AIS for each body segment. For comparison an average injury severity value has been evaluated for each body segment by using the expression $\Sigma \text{AIS}^2 / N$, a method which also has been employed by Walfish et al (8). By using this parameter the head, thorax and abdomen exhibit the most severe injuries as can be expected; - the values being higher for the unbelted occupants. Furthermore, the drivers tend to score higher values. This fact is pronounced concerning the head injuries in the belted group and concerning the thorax injuries in the belted as well as in the unbelted group. These expected findings, also reported by Harris et al (9), Shanks et al (2) a.o., show that the steering wheel and the dashboard account for severe injuries in belted as well as in unbelted front seat occupants, i.e. seat belts cannot restrain sufficiently from contact with the interior of the car.

Fig. 4 illustrates the frequency of mild (AIS=1-2), moderate (AIS=3-4) and severe or fatal (AIS=5-6) for the body segments head, thorax and abdomen respectively. Also in this representation the higher frequency for severe injuries is evident. Severe thorax and abdominal injuries are significantly lower (** level) in the belted group.

Seat belt use versus age

The seat belt use as a function of age is presented in fig 5. The material has been subdivided into three groups of the same size regarding the number of persons. Sixty-one per cent of the front seat occupants use seat belts and women more often than men (64% and 59% respectively). This difference is not significant. There is however a marked correlation between seat belt use and age. Group I (45.7% seat belt use) differs significantly from the average level, and so does group III (70.8% seat belt use). It should be noted that 9 persons under 15 are included in group I, and therefore were not under the seat belt law. Anyhow, significant difference is maintained when these persons are excluded.

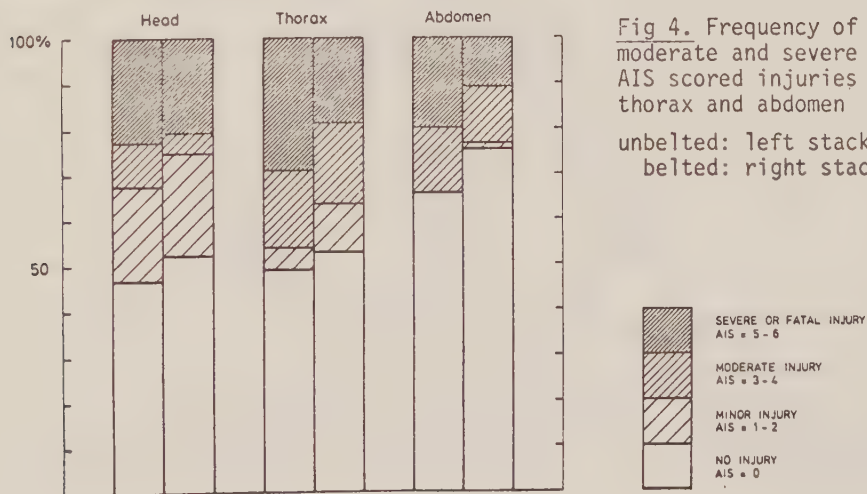


Fig. 4. Frequency of mild, moderate and severe or fatal AIS scored injuries to head, thorax and abdomen

unbelted: left stack
belted: right stack

Average ISS for belted and unbelted front seat occupants versus age

It is a well known fact that biological material loses strength with age. Baker et al (10) have shown a positive correlation between ISS and age. This is readily illustrated in the present material too, cf table 3 and fig 5 b, where the average ISS is presented as a function of age for the belted and unbelted front seat occupants. Concerning the protective effects of the seat belts there is a significant reduction of the ISS, on the ** level in group II and on the * level in group III, while no significant difference can be detected in group I.

For the belted as well as for the unbelted front seat occupants there is a positive correlation between the ISS and the age. Concerning the seat belt users the ISS is significantly lower for group I and II compared to group III and for the unbelted there is a significant difference for group I compared with group II and III. The ISS versus age correlation is further confirmed by the fact that group I is involved in more violent accidents measured by the impact energy parameter used. The car damage is significantly higher (** level) in group I compared to group II, cf. table 3.

Age group	Average ISS		Average car damage
	belted N= 443	unbelted N= 288	
I	18.5	23.3	22.5
II	21.3	36.7	17.8
III	29.9	37.6	21.8

Table 3. Average ISS and average car damage for belted and unbelted front seat occupants correlated to age. I: age < 25 years, II: 25 years < age < 50 years, III: age >50 years.

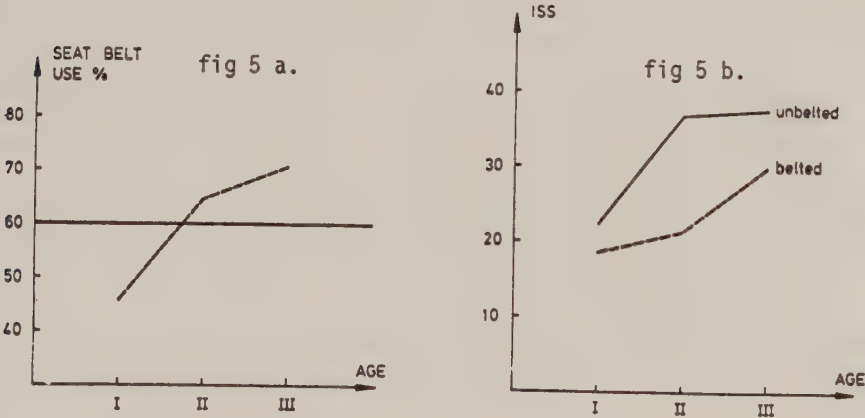


Fig 5 a, b. a) seat belt use correlated to age in front seat occupants; b) average ISS and average car damage for belted and unbelted front seat occupants correlated to age. I: age < 25 years, II: 25 years < age < 50 years, III: age > 50 years.

ISS and impact direction

The influence of the impact direction has been studied for the driver and the front seat passenger separately. Four main impact directions have been used: head-on, right and left side, and roll over. Impacts from behind are few and have not been studied. A roll over accident is considered as soon as the car has rolled on the side or top, irrespective of any initial clockwise direction. The frequency of the impact directions in the accidents studied are evident from fig 6.

The average ISS is presented in table 4. From the figures it is evident that seat belt use reduces the injury severity. In head-on collisions there is a significant difference for the driver and the passenger. In head-on collisions the average injury severity for belted drivers is somewhat higher compared with that for belted front seat passengers. This difference should be attributed to the steering column.

In side impacts significant difference is found concerning reduction of injuries to the opposite side occupant. No negative effects of seat belts could be found in side impact collisions. These results are in good agreement with those of Danner (11), who has studied the injury characteristics of belted occupants in side collisions.

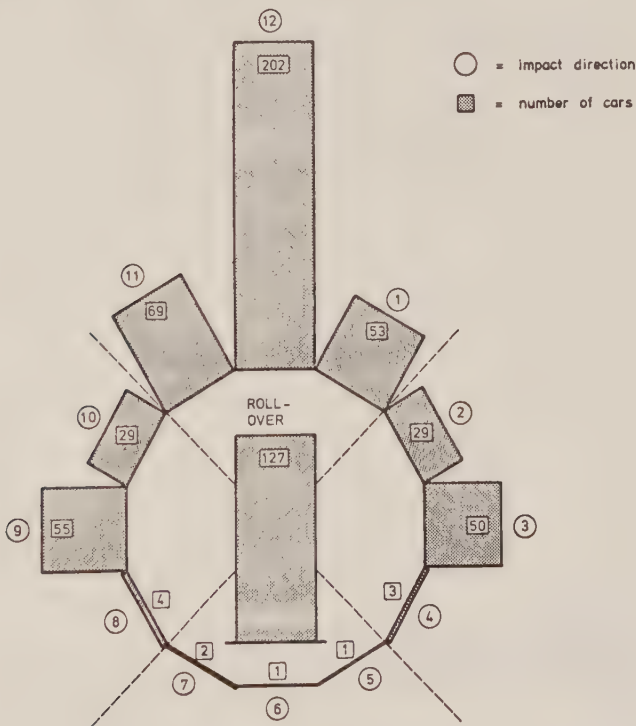


Fig 6. Frequency of accident impact direction

Impact direction	Number	Driver		unbelted ISS	Significance level
		belted ISS	Number		
11, 12, 1	168	22.0	93	29.5	*
2, 3, 4	45	19.1	22	25.5	*
8, 9, 10	47	44.1	25	51.8	-
roll over	34	21.4	44	32.1	-

Front seat passenger					
11, 12, 1	80	16.8	52	29.9	**
2, 3, 4	29	42.7	13	53.8	-
8, 9, 10	22	14.1	12	30.3	*
roll over	15	21.3	25	11.9	-

Table 4. Average ISS in belted and unbelted drivers and front seat passengers correlated to accident impact direction.

ISS correlated to relative accident impact energy for drivers and front seat passengers

Bartz et al (12) have correlated the collision speed and the severity of occupant injury. For this purpose they recommend that preference should be given to the ISS system of grading injuries when classifying the severity of an accident. The collision speed is suitable when impact energy is to be calculated. However, in our case, as in many others, it is impossible to estimate the collision speed. This is why the deformation of the cars involved has been chosen for the calculation of a relative impact energy (IE). Fig. 7 presents the distribution of the relative impact energy in the accidents studied.

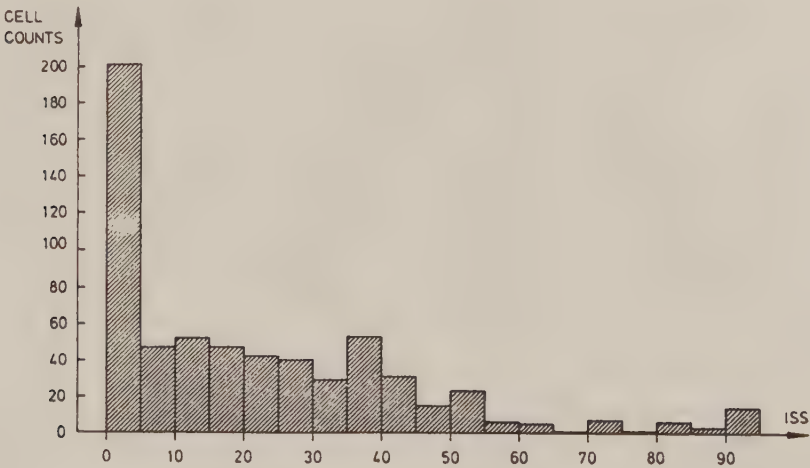


Fig 7. Distribution of car damage. N=625

In fig. 8 the variation of the ISS in relation to the impact energy is presented for belted and unbelted drivers and front seat passengers. A gliding average has been used to smoothen the ISS graph. In addition the number of belted and unbelted front seat occupants in relation to the impact energy is indicated too.

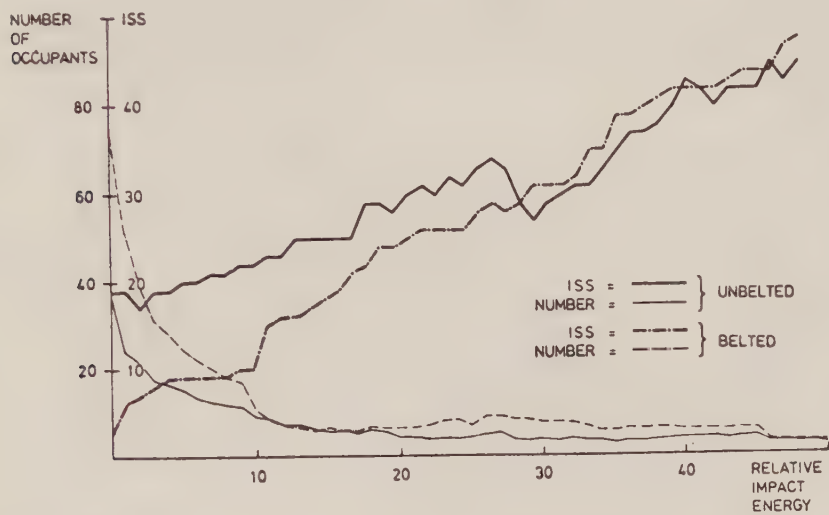


Fig 8. ISS in belted and unbelted front seat occupants correlated to relative impact energy.

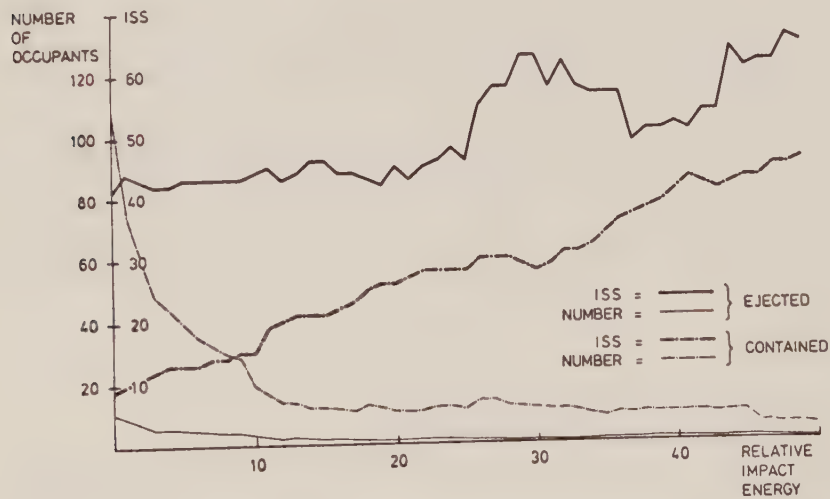


Fig 9. ISS in front seat occupants (belted and unbelted) confined to the car or ejected, correlated to relative impact energy.

For impact energy values below 11 units there is a ** significant difference between the injuries in the unbelted and the belted group. The average difference is about 10 ISS units which corresponds to an AIS value of three i.e. a severe, not life threatening injury in one body region, e.g. spinal injury involving C-4 and below, lung contusion, abdominal or organ contusion, comminuted and/or open fractures of long bones, pelvic fractures etc. or to an AIS value of two in three different body regions. For high energy accidents the difference of the ISS scored injuries suffered by belted and unbelted front seat occupants tend to diminish as can be expected. As the deformation of the car gradually becomes greater, the protective effects of the seatbelt will not longer be at hand.

Ejection from the car and the benefit of the seat belts to prevent ejection has been discussed by many authors. In fig. 9 the same ISS impact energy relation as the one used above is presented, but this time for front seat occupants confined to the car (belted and unbelted) in comparison with occupants ejected from the car during the accident. It is, of course, difficult to compare the pattern of injury in a group of ejected persons with a group of persons confined in the car, as the "environmental" factors are not comparable. However, by using the present representation it is possible to study the difference in injury severity for a person confined and a person ejected. In the present material nearly all of those ejected did not wear seat belts. Ejection almost always involves fatal injuries. From fig. 9 it is evident that a considerable reduction in injuries can be expected if the occupants are confined to the car. Thus, one of the most important effects of seat belt use is the prevention from ejection.

Conclusions

Results of this investigation indicate that:

Fatalities in accidents occur in spite of and not because of seat belt use. Seat belt use reduces the likelihood of severe injuries to occupants for most types of occupant or crash circumstances.

It is much better to remain in the car during the crash than to be thrown out. Notwithstanding seat belt use prevents ejection, this is true whether seat belts are used or not.

Steering columns and dashboards remain a threat to lives. Skull and brain injuries are not substantially reduced with seat belt use in front seat occupants.

Seat belts reduce severe and moderate injuries to a greater extent than they save lives.

Injury severity is strongly dependent of age.

It is doubtful whether improved emergency medical care can considerably reduce the number of fatalities.

References

- 1) Huelke H.W. et al: Effectiveness of current and future restraint systems in fatal and serious injury automobile crashes. SAE paper 790323, 1979
- 2) Shanks J.E., Thompson A.L.: Injury mechanisms to fully restrained occupants. Proc. 23d. Stapp Car Crash Conference, paper 791003. SAE inc. 1979.
- 3) Cameron M.H., Nelson P.G.: Injury patterns with and without belts. Proc. 6th Int. Conference of the Association for Accident and Traffic Medicine, pp. 423-479, Melbourne 1977.
- 4) Da et al: Draept i bil. Ulykksårsager og selevirkning. Retsmedisinsk institut, Århus & Rådet før trafiksikkerhedsforskning, Rapport 21, 1977.
- 5) Baker S.P. et al: Injury Severity Score: A method for describing patients with multiple injuries and evaluating emergency care. J. of Trauma, 14: 187-196, 1974.
- 6) Langwieder K.: Passenger injuries in collisions and their relation to general speed scale. 17th. Stapp Car Crash Conference, paper 730963, SAE inc. 1973
- 7) Voigt G.E.: Die Biomechanik stumpfer Brustverletzungen, besonders von Thorax, Aorta und Herz. Hefte Unfallheilk., 96: 1-115, 1968.
- 8) Walfish G. et al: Synthesis of abdominal injuries in frontal collisions with belt-wearing cadavers compared with injuries sustained by real-life accident victims. Problems of simulation with dummies and protection criteria. Proc. IVth. International IRCOBI Conference, pp. 151-164, Gothenburg, 1979.
- 9) Harris L.S., Whright R.K.: Injuries fatal to occupants using seat belts. Proc. 18th. Conference of the AAAM, pp. 30-36, 1974.
- 10) Baker S.P. et al: Injury Severity Score: development and potential usefulness. Proc. 18th. Conference of th AAAM: pp. 58-72, 1974.
- 11) Danner J.M. Accident and injury characteristics in side-collisions and protection criteria in respect of belted occupants. Proc. 21th. Stapp Car Crash Conference, paper 770918, SAE inc., 1977.
- 12) Bartz J., Mattern R.: Injury Severity Score (ISS) und Kollisionsgeschwindigkeit als Parameter für die Unfallschwere. Beitr. Gerichtl. Med. 37: 177-181, 1979.

The Effect of the Unrestrained Back Seat Passenger on the Injuries Suffered by Drivers and Front Seat Passengers in Head-on Collisions

P. Löwenhielm and P. Krantz

Dept. of Forensic Medicine, University of Lund, Sölvegatan 25, S-223 62 Lund, Sweden

Summary. In head-on collisions, loose items in the rear of the car, such as luggage or unrestrained back seat passengers can cause substantial loading on the back of the front seats. The purpose of this paper is to study if such loading increases the injury severity for the front seat occupants. Data were collected from all fatal automobile accidents for a period of 1 year in Sweden. Information was collected about the survivors as well as the deceased. Head-on collisions were selected, and the injuries of the front seat occupants were scored according to the Abbreviated Injury Scale (AIS) and the Injury Severity Score (ISS). In evaluating the injury severity, the collision energy was taken into account. The results indicate that belted front seat passengers sustain a higher injury risk with an unrestrained passenger in the back seat. These results are valid for collision speeds below 45 km/h.

Key words: Car occupant – Head-on collision – Injury severity – Seat belt loading

Zusammenfassung. Bei Frontalkollisionen können lose Gegenstände auf den Rücksitzen von Personenkraftwagen – wie Gepäck, nicht angegurte Passagiere – zu einer erheblichen Belastung der Rücklehne der Vordersitze führen. In der vorliegenden Studie wird untersucht, ob durch eine derartige Belastung die Schwere der Verletzungen bei Vordersitzinsassen erhöht wird. Die erforderlichen Daten stammen von sämtlichen Kraftwagenunfällen mit tödlichem Ausgang, die sich während 1 Jahres in Schweden ereignet haben. Die Angaben betreffen auch die Überlebenden, und die Körperverletzungen beim Fahrer und Beifahrer auf dem Vordersitz der Fahrzeuge wurden entsprechend der „Abbreviated Injury Scale“ (AIS) und der „Injury Severity Score“ (ISS) aufgeschlüsselt. Bei der Bestimmung der Verletzungsschwere wurde die Kollisionsenergie berücksichtigt. Die Resultate deuten darauf hin, daß die Fahrzeuginsassen auf den Vordersitzen einem größeren Verletzungs-

risiko ausgesetzt sind, wenn sich ein nicht angegurter Insasse auf dem Rücksitz befindet. Dieses Resultat gilt für Kollisionsgeschwindigkeiten unter 45 km/h.

Schlüsselwörter: Frontalkollision, Verletzungsrisiko auf den Vordersitzen bei nicht angegurten Insassen auf den Rücksitzen – Traumatologie, Verletzungen bei Frontalkollision

Legislation made seat belt use compulsory in Sweden in 1975, but applied to front seat occupants only. Taxis were not included. Objections to the exceptions have been raised as it is assumed that objects in the back seat, e.g., unrestrained passengers, luggage, or dogs, may increase the risk of injury to the front seat occupants, especially in head-on collisions. Bohlin (1977) considered that unbelted back seat occupants provide a main injury risk to the front seat occupants. Niederer et al. (1977), Nahum et al. (1967), and Mackay et al. (1975) have shown evidence of overloading of the front seat occupants by back seat passengers. As the use of seat belts on the back seat is quite uncommon in Sweden, the above mentioned effects should be expected in automobile accidents in the Swedish environment, too. To study this, the present investigation evaluated all fatal automobile accidents in the whole of Sweden in 1975.

Material and Methods

The basic data were compiled from 458 accidents involving 1,366 persons, of whom 560 were killed at the scene of the accident or died within 1 year of their injuries. Accident data relevant to the dead as well as to the injured who survived were collected from police reports, photographs from the scene of the accident, as well as of the damaged cars, autopsy reports, and medical records.

From these basic data the head-on collisions were selected, i.e., accidents with an 11, 12, or 1 o'clock direction of impact. Occupants of cars that were driven under lorries or occupants who were thrown out of cars were excluded.

The injuries of the front seat occupants were grouped according to the *type* (i.e., aortic rupture, skull fracture, etc.), the *location* (head, neck, thorax, etc.), and the *seriousness*. In evaluating the seriousness, the Abbreviated Injury Scale (AIS, 1976 revision) was used. For the overall injury assessment, the Injury Severity Score (ISS) was applied.

When the severity of a collision is to be assessed, the change in velocity of the impact is the most suitable variable. The absolute velocity change is never known with accuracy. The velocity change is, however, usually proportional to the degree of deformation of the car; consequently, an assessment of deformation should provide a useful tool to estimate the energy dissipated during that phase of the accident when the body injuries are likely to occur.

To comprehend the energy of impact, the deformation of different zones of the cars was estimated, and the deformation score for each zone was squared and the squares were added together. The value thus achieved represents the energy of impact. This approach was described by Krantz and Löwenhielm in 1980. In this matter, the weight of the back seat passengers should also be considered. The majority of the back seat passengers survives the accidents, and in the medical records collected, information on the weight of the patient was, as a rule, lacking. Thus, the potential effect of a variable loading of the front seat occupants caused by different weights of the back seat passengers has not been taken into consideration in the present study. There was no positive information on loose items (i.e., luggage) in the back seat in any of the cases studied.

Table 1. Number of drivers and front seat passengers in head-on collisions related to seat belt use and presence of back seat passenger behind

	Seat belt used	Seat belt not used	Seat belt users
Driver with back seat passenger behind	36	22	62%
Driver without back seat passenger behind	139	71	66%
Front seat passenger with back seat passenger behind	25	18	58%
Front seat passenger without back seat passenger behind	55	32	63%

Table 2. Average ISS for front seat occupants with and without unrestrained passenger behind in relation to seat belt use. Frontal collisions

	Seat belt used (ISS)	Seat belt not used (ISS)
Driver with back seat passenger behind	23.4	31.3
Driver without back seat passenger behind	22.7	29.9
Front seat passenger with back seat passenger behind	21.2	26.3
Front seat passenger without back seat passenger behind	15.1	31.7

Results and Discussion

Of 261 back seat occupants, 11 (4.4%) were restrained. It is significant that these 11 persons all survived the accidents, whereas 60 of the 250 (24%) unrestrained back seat occupants were killed.

If alone, the unrestrained back seat passenger sits in the middle of the back seat sometimes. In these cases "sitting behind" was defined as true for the driver in an 11 o'clock collision, as true for the front seat occupant in a 1 o'clock collision, and not true for either of the front seat occupants in a 12 o'clock collision. There were only left-hand-driven cars in this investigation. Considering these distinctions, there was an unrestrained back seat occupant behind the driver or the front seat occupant in 25% of the cases (101 of 398 persons) (Table 1).

Twenty-five per cent is near to the frequency of 23% given by Niederer et al. (1977). Of the 139 belted drivers, 131 wore 3-point lap-shoulder belts, seven wore 2-point lap-belts, and in one case it could not be established which type had been worn. The corresponding figures for the 55 belted front seat passengers were 48, 2, and 5, respectively.

Table 3. Average relative impact energy sustained by front seat occupants with and without unrestrained passengers behind in relation to seat belt use. Frontal collisions

	Seat belt used (impact energy)	Seat belt not used (impact energy)
Driver with back seat passenger behind	18.5	16.3
Driver without back seat passenger behind	14.5	15.7
Front seat passenger with back seat passenger behind	21.5	12.9
Front seat passenger without back seat passenger behind	18.6	16.8

Table 4. Average ISS for restrained and unrestrained front seat occupants with and without unrestrained passengers behind in relation to relative impact energy level. Frontal collision

	Relative impact energy interval			
	0-1 ISS	2-10 ISS	11-30 ISS	> 30 ISS
Driver with back seat passenger behind	8.2	21.2	28.4	48.8
Driver without back seat passenger behind	7.2	22.5	29.1	46.1
Front seat passenger with back seat passenger behind	1.3	25.5	30.5	31.9
Front seat passenger without back seat passenger behind	4.8	22.9	26.9	30.2

In Table 2, the average ISS for the drivers and the front seat passengers in head-on collisions is presented. Except for the unbelted front seat passenger group, there seems to be a slight increase in the injury severity when there was an unbelted passenger in the back seat. This increase/decrease must be judged with reference to impact energy. In Table 3, the average impact energy is indicated for the groups defined in Table 2. Comparing the values given in Tables 2 and 3, it is evident that there is a positive correlation between the ISS and the impact energy, i.e., for all the groups there is an increase of injury severity when the impact energy increases. Thus, it is not possible to compare the groups when the impact energies differ significantly. On the other hand, the injury reducing effect of the seat belt is apparent from Tables 2 and 3. In this case, there is a negative correlation between ISS and impact energy except for the drivers without an unbelted passenger in the back seat. In this case, the impact energies are of the same magnitude and can be compared anyhow. Krantz and Löwenhielm (1980) presented an investigation on the injury-reducing effect of seat belts, showing

Table 5. Injuries scaled according to AIS in restrained front seat passengers without and with unrestrained passenger behind in the relative impact energy interval 2-10 (< 45 km/h), frontal collision

Restrained front seat passenger with unrestrained passenger behind								
Region	N	AIS						
		0	1	2	3	4*	5	6
Head	5	3	0	0	0	0	0	2
Thorax	5	1	0	0	1	2	0	1
Abdomen	5	4	0	1	0	0	0	0

Restrained front seat passenger without unrestrained passenger behind								
Region	N	AIS						
		0	1	2	3	4	5	6
Head	12	6	1	4	1	0	0	0
Thorax	12	10	0	0	2	0	0	0
Abdomen	12	10	0	0	0	1	1	0

that the ISS was related to the impact energy. This method was applied in the present investigation. Krantz and Löwenhielm (1980) found that a critical level for fatal injury was about ISS = 25. Referring to Table 2, this value falls between the belted and the unbelted groups.

To take the impact energy dependence into consideration, four energy levels were chosen as there were not many cases. To obtain groups of comparable sizes the four groups were defined as follows: (1) minor or no impact, IE = 0-1; (2) moderate impact, IE = 2-10; (3) powerful impact, IE = 11-30, and (4) very powerful impact, IE > 30. In Table 4, the average ISS vs the relative impact energy is presented.

Impact energy 10 corresponded to a velocity of about 45 km/h. The ISS for the driver groups correlated well with the energy levels studied. For the front seat passengers, the ISS values were somewhat higher when there was an unrestrained passenger behind, but this difference was not significant. For lower impact energies, the results for the drivers and the front seat passengers were quite comparable, but as the impact energy increased a significant difference was obtained. The reason for this difference was that the driver in high velocity accidents reached the steering wheel, irrespective of the seat belts being used or not. In a restrained position, the driver's head often hit the steering wheel. Mackay et al. (1975) indicated that in a sample of simple frontal collisions, over 60% of the drivers wearing seat belts struck the steering wheel with their heads. Rattenbury (1979) found that about 50% of the drivers struck the steering wheel when the speed was about 50 km/h. The use of seat belts was not taken into consideration in the results presented in Table 4. No marked change in injury severity was obtained if the use of seat belts was taken into account, but for two groups:

restrained front seat passengers with and without an unrestrained back seat passengers behind and in the impact energy interval $IE = 2-10$. With 5 and 12 persons, respectively, these groups were small. It was not purposeful to apply statistical methods to such small test groups. The specific injuries in the groups, however, gave some information. In Table 5, the injuries are presented for the head, thorax, and abdomen—scaled according to AIS. The most striking differences were that more serious injuries to head and thorax were suffered by the front seat passengers with an unrestrained passenger behind. Two persons in this group were killed, whereas all of the front seat passengers without a passenger behind survived the accidents. Although it was impossible to ascertain an increased risk of additional injury to the front seat occupants, caused by unrestrained passengers in the rear of the car, it should be recalled that the basic data of this investigation were gathered from fatal accidents. However, the results obtained for the passenger group suffering impact energy of 2–10 may indicate that the possible benefits of reducing overloading of the front seat occupants are obtained in collision velocity changes below 45 km/h.

References

- Bohlin N (1977) Fifteen years with the three-point safety belt. Proc 6th IAATM Conf, Melbourne, p 142
- Krantz P, Löwenhielm P (1980) Injury response in belted and unbelted car occupants related to the car crash energy in 458 accidents. Proc 5th IRCOB Conf, Birmingham, p 305
- Mackay GM, Gloyns PF, Hayes HRM, Griffiths DK, Rattenbury SJ (1975) Serious trauma to car occupants wearing seat-belts. Proc 2nd IRCOB Conf, Birmingham, p 20
- Nahum AM, Siegel AW, Hight PV (1967) Injuries to rear seat occupants in automobile collisions. Proc 11th Stapp Car Crash Conf, Society of Automotive Engineers (SAE), p 159
- Niederer P, Walz F, Zollinger U (1977) Adverse effects of seat-belts and causes of seat-belt failures in severe car accidents in Switzerland during 1976. Proc 21st Stapp Car Crash Conf, Society of Automotive Engineers (SAE), p 53
- Rattenbury SJ, Gloyns PF, Hayes HRM, Griffiths DK (1979) The biomechanical limits of seat belt protection. Proc 23rd AAAM Conf, Louisville, KY, p 162

Received September 21, 1983

HEAD AND NECK INJURIES TO MOTORCYCLE AND MOPED RIDERS- with special regard to the effect of protective helmets

by

K. Peter G. Krantz

SUMMARY

In a consecutive series of 132 autopsied mc and moped riders killed in 1977-1983 in southern Sweden, almost half of the fatal head and neck injuries occurred remote from the point of impact i.e. certain intracranial injuries without fractures, ring fractures of the base of the skull, disruption of the head-neck junction and cervical spine injuries. Ring fractures of the base of the skull were significantly more frequent compared with killed car occupants. Injuries observed remote from the point of impact were often the result of impacts against the anterior part of the head, especially against the face. The finding that all 6 riders suffering disruption of the head-neck junction were helmeted indicates that the helmet might promote such injuries. In some of these cases no sign of impact against the head could be detected. A whiplash mechanism, enhanced by the helmet, is supposed to contribute to the origin of some of these injuries. Thus, the protective ability of the helmet against these injuries is doubtful.

Fatal head injuries to the point of impact were mostly found in the lateral-posterior part of the head. These injuries were often irrespective of helmet use. The points of impact were mainly found in a hat-band like zone around the head. Protective helmets should be improved in order to give better protection against injuries at the trauma site especially in the above mentioned area, better protection to the face and increased energy absorbing capacity. Concomitant with these improvements, the helmet mass must be reduced, otherwise the injuries are likely to transfer from the site of impact to the head-neck junction.

INTRODUCTION

During the last few years, the trend of continuously increasing number of traffic fatalities was broken in many countries in the western world. Important factors for this development are changed driving patterns probably due to rising fuel prices and improvements of road systems and vehicles. Among one group of road users, mc riders, the trend is however the opposite. The number of mc:s on the road is increasing continuously and they are becoming more and more powerful. Car occupants benefit from the improved interior safety of the cars. The possibilities of protecting riders of motorized two-wheel vehicles (mtwv) are very limited.

The most common cause of death among mc and moped riders are injuries to the head and neck (Graham, 1969). The use of protec-

tive helmets is believed to decrease the number and severity of head injuries among riders involved in accidents. Consequently, the use of helmets became compulsory in many countries in spite of the fact that little is actually known about the way in which those injuries arise. Despite the use of helmets, injuries to the head and neck still occur. Does the protective helmet influence the type of injury to the head and neck? If so, in what way?

Based upon the autopsy findings of a consecutive series of killed mc and moped riders, this investigation is an attempt to classify those injuries among such road users. Interest has been focused on the use and non use of helmets among the killed riders, to establish the influence of the helmet on the type of injuries. When working on helmet improvements, this knowledge is probably of crucial importance.

MATERIAL AND METHOD

In all cases of traffic fatality in southern Sweden autopsies are performed at the Department of Forensic Medicine in Lund. During a 7-year-period (1977 - 1983), 132 mc and moped riders were killed in this area. Forty helmets of the 102 asked for, were obtained for examination. The bases for forming a judgement of the mechanism of the injuries were the autopsy findings, the police reports including photographs from the scene of the accidents and in some cases, hospital records as well. In a few cases, conversations with relatives completed the information about helmet wearing.

Head and neck injuries of the victims were scrutinized. The upper cervical vertebrae were examined after dissection of the soft tissue between the atlas and the base of the skull from behind. The cervical spine surrounded by muscles and ligaments together with the posterior part of the base of the skull were in some cases preserved, frozen and cut in the sagittal mid-plane in order to reveal possible injuries. In these cases, the bony parts were macerated afterwards. The brain was always removed ad modum Flechsig (Voigt and Saldeen, 1968) which allows examination of the parasagittal bridging veins.

RESULTS

During the studied period (7 years), there were 72 mc and 60 moped riders killed, in all 132 riders. Since there are roughly 1.8 million inhabitants in the area, and the average number of accidents was 19 per year, the number of fatal accidents of this type per year was 1 per 100.000 inhabitants. Among those 132 killed, 70 of the mc riders and 32 of the moped riders (102 riders in all) had been wearing helmets when the accidents occurred. Two mc riders and 28 moped riders were not wearing helmets. (The wearing of helmet became compulsory by law for moped riders in September 1, 1978). Thirty-eight of the helmeted mc riders had been wearing full face helmets (FF-helmets) and 32 open face helmets (OF-helmets). All helmeted moped riders had been wearing OF-helmets. The distribution of the age

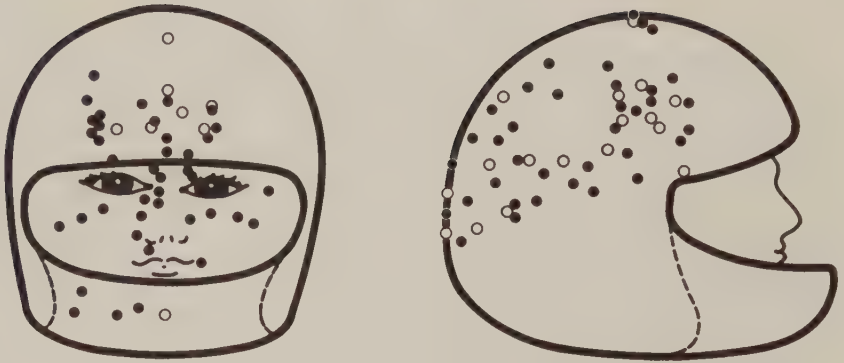
of the riders does not differ from that reported by others (Drysdale et al., 1975, Mätzsch, 1983). The mc riders were generally young. Among the moped riders, 23 were about 15 years old and the majority (35 cases) were more than 50 years old.

In Sweden, mopeds have a permitted maximum speed of 30 km/h. Motorcycles are restricted by the general speed limits: 50 km/h in towns and villages, 70 km/h on lesser roads, 90 km/h on major roads and 110 km/h on highways. The types of accidents in the material agree with the findings of other authors (Drysdale et al., 1975, Mätzsch, 1983). Five of the mc single vehicle accidents were collisions with mooses.

Nineteen of the 40 examined helmets were OF-helmets. They had a weight of 650 - 1.000 g. Twenty-one were FF-helmets weighing 1.150 - 1.500 g. The damage to the helmets were compared with the injuries of their owners. It was, however, difficult to determine whether the often stated minor abrasions of the helmet-shells were caused by the accident in question or if they represented older lesions. Major damage like tears and indentations of the shell or the interior lining were always a result of the studied accident. In some single cases, only the chin-straps were teared apart. The helmets were probably detached in some cases, but the exact number was difficult to establish as it was often impossible to determine if the helmet had been removed from the victim's head shortly after the accident by helpful fellow road users or not.

Point of impact.

Impacts against the head were seen in almost all cases. There was one case of fatal aspiration of blood owing to impact against the neck causing severe injuries to the larynx. The basis for stating the points of impact was the injuries to the head and the damage to the helmet. In a few cases damage to the cars involved in collisions with the mtwv contributed to establishing the points of impact of the head. In 76 cases of helmeted riders and in 25 of riders without helmets (see fig.1), it was possible to determine the points of impact of the head. In 11 cases it was impossible to determine the points of impact of the head. In 5 of these cases there were no external signs of impact and in the remaining 6 cases, it was impossible to decide which one of the injuries represented the major impact. Almost half of the riders (48 of 101) suffered impact to the anterior third of the head (defined laterally by the limits of the face-opening) and in the rest of the cases the impact occurred on the right (21 cases) or left (32 cases) lateral-posterior part of the head. Points of impact were seen at all levels from the chin to the vertex, but impacts below the level of the ears were rare. Thus, one could say that the points of impact were situated at the anterior part of the head, mainly in the face, or primarily within a zone around the head, corresponding to a hat-band.



- *Helmeted riders*
- *Riders without helmet*

Fig. 1. Point of impact in 76 helmeted riders and 25 riders without helmets.

Injuries.

The injuries could be divided into 3 different groups according to the type of injury and site of impact:

1. Minor or no injuries to the head and neck (20 cases - 15 %)
2. Injuries to the head at the point of impact (64 cases - 49 %)
3. Injuries to the head and neck remote from the point of impact (48 cases - 36 %)

Starting from the appearance of the injuries, the groups were subdivided, thus making the analyses of the injury mechanism behind these accidents possible. The best way of demonstrating the points of impact is by means of the appearance of the fractures. This forms the basis of the division of the material into groups 2 and 3. In almost all cases, there were, however, concomitant soft tissue injuries and central nervous lesions. Some injuries - e.g. disruption of the parasagittal bridging veins - gave information about the points of impact. The above mentioned groups 2 and 3 were subdivided as follows:

- 2.1. Head totally crashed (1 helmeted rider and 4 without helmets; 5 cases, 4%).
- 2.2. Depressed-comminuted fractures (18 helmeted riders and 6 without helmets; 24 cases, 18%).
- 2.3. Linear vault fractures (23 helmeted riders and 9 without helmets; 32 cases, 25%).
- 2.4. Cortical cerebral contusions without fractures (2 helmeted riders and 1 without helmet; 3 cases, 2%).
- 3.1. Other intracranial injuries without fractures (15 helmeted riders and 1 without helmet; 16 cases, 13%).

- 3.2. Ring fractures of the base of the skull (17 helmeted riders and 4 without helmets; 21 cases, 16%).
- 3.3. Disruption of the head-neck junction (6 helmeted riders; 5%).
- 3.4. Injuries to the cervical spine without head injuries (3 helmeted riders and 1 without helmet; 4 cases, 3%)

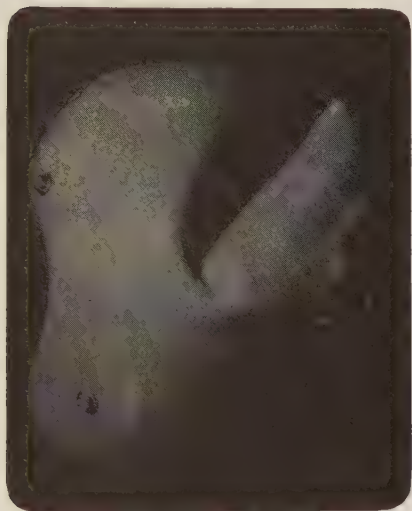


Fig.2. Indentation in a helmet of a rider suffering a depressed-comminuted fracture of the skull.

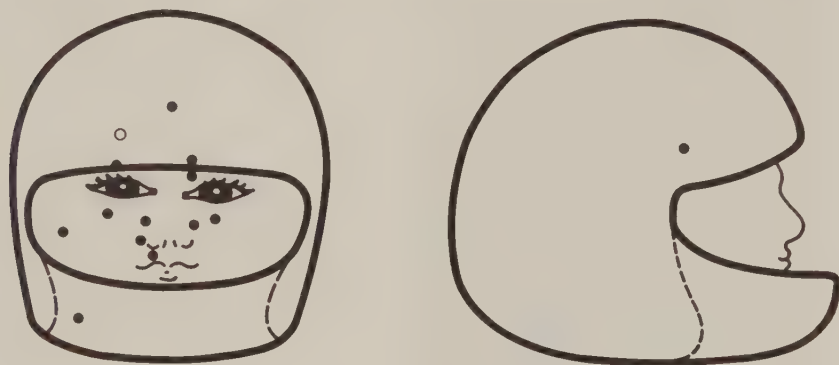
Injuries to the head at the point of impact.

The injuries to the riders of the above mentioned groups 2.1 - 2.4 appear at the point of impact. Among the 60 riders suffering this type of injury where the points of impact could be stated, the points of impact were found in 42 cases in the lateral-posterior part of the head. Judging from helmet damage, riders whose heads were totally crashed or suffered depressed-comminuted fractures had all been victims of severe force against the head. In all these cases, fractures to the base of the skull, cortical lacerations and disruption of numerous parasagittal bridging veins were seen concomitantly. In two cases, the depressed-comminuted fractures of the forehead resulted in fractures of the base of the skull with a complete ring appearance (wedge effect; Voigt and Sköld, 1974). Fourteen of the 24 depressed-comminuted fractures appeared at the lateral-posterior part of the head. The injuries had a similar appearance irrespectively of whether the rider had been wearing a helmet or not. These helmets showed either cracks - or in cases of helmet shells made of polycarbonate - severe indentations (see fig 2). The mechanisms behind linear vault fractures and isolated cortical contusions are similar to those of the depressed-comminuted fractures though they have suffered a force of a lower magnitude judging from the moderate and sometimes insignificant damage to their helmets. Most of the linear vault fractures proceeded into the base of the skull. Twenty-two of these 32 linear vault fractures were found in the

lateral-posterior part of the head. Helmet wearing appears not to have played any decisive role in the occurrence of these types of injury.

Injuries to the head and neck remote from the point of impact.

Other intracranial injuries without fractures.



- *Helmeted riders*
- *Riders without helmet*

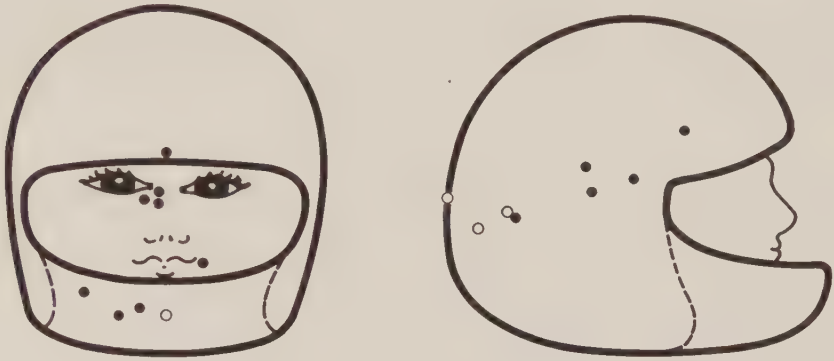
Fig.3. Point of impact in 13 helmeted riders and 1 rider without helmet suffering intracranial injuries without fractures.

This group consists of three different types of injuries: (1.) Central cerebral haemorrhages, (2.) disruption of parasagittal bridging veins sometimes accompanied by (3.) gliding contusions (cortical or subcortical haemorrhages at the upper margin of the frontal and parietal lobes). Sixteen of the 17 riders in this group were helmeted. Eleven were wearing OF-helmets and 5 FF-helmets. Seven of the 17 riders suffered disruption of numerous or all of the parasagittal bridging veins. In 13 of those 14 cases where it was possible to determine the point of impact, the rider had been hit in the face or close to the face. Such points of impact close to the face were often covered by the helmet (see fig. 3). In 1 rider only, the point of impact was found in the temporal part of the head. Minor haemorrhages were found in the leptomeninges.

Ring fractures of the base of the skull.

Apart from the above mentioned 2 cases of ring fractures due to depressed-comminuted fractures in the forehead, 3 different types of ring fractures were found: Ring fractures due to (1.) traction or (2.) torsion of the upper part of the head in relation to the base of the skull and (3.) ring fractures due to displacement of the atlas, and parts of the base of the skull, localized around the foramen magnum, into the skull. The origin

of the fractures were mostly revealed by motion-tests at autopsy. In those cases, the soft tissue often only permits movement in the same direction as that of the impact force. Seventeen of the 21 riders suffering these injuries were helmeted (81%). Five of them wore OF-helmets and 11 FF-helmets. In 1 case, the type of helmet could not be determined. The points of impact are seen in fig. 4.



- *Helmeted riders*
- *Riders without helmet*

Fig.4. Point of impact in 13 helmeted riders and 4 riders without helmets suffering ring fractures of the base of the skull.

Ring fractures of the base of the skull due to traction are the result of a force which lifts the upper part of the head in relation to the base of the skull and are often associated with an angular acceleration of the head. For 9 of the riders suffering this type of ring fractures the point of impact was the anterior part of the head; in 4 cases the chin, and in 4 cases the central part of the face and in 1 case the forehead. In 2 cases the point of impact was the posterior and in 2 cases the lateral part of the head. There were 3 cases without signs of impact which only showed some minor abrasions from the chin-strap (2 riders wearing FF-helmet, 1 rider wearing OF-helmet). Both FF-helmets were obtained for examination. They were undamaged.

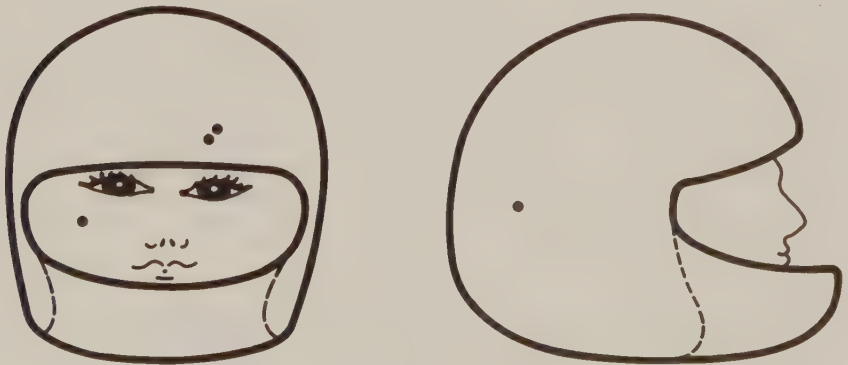
Ring fractures of the base of the skull due to torsion are mostly seen as the result of oblique impact against the temporal or posterior part of the side of the head resulting in rotation around a vertical axis of the upper part of the head in relation to the base. The appearance of the ring fracture is consequently assymetric with fractures of the lateral part of the head at different levels (Voigt and Sköld, 1974). In the material, 2 such cases were found. For 1 of the 2 riders the point of impact was the left temporal part of the head and for the other, the posterior left part of the head.

Some ring fractures of the base of the skull are caused by impact against the top of the head causing displacement of the atlas and thereby the bone around the foramen magnum into the skull. Three such fractures were found. In 1 case, the point of impact was the posterior part of the vertex, in another one the lateral part of the head and in the third case it was impossible to determine the exact point of impact.

All riders suffering ring fractures sustained severe brain injuries. A number of cases with ring fractures caused by traction or torsion showed complete disruption of the brainstem between the pons and the oblonged medulla. Disruptions of some, numerous or all parasagittal bridging veins were invariably found in such cases.

Disruption of the head-neck junction.

This injury consists of disruption of the capsule and ligaments of the atlanto-occipital joint. In some cases, parts of the occipital joint surface were torn off and were connected to the joint capsula. Six riders suffered this injury. All wore OF-helmets. Three of them suffered impact to the anterior part of the head and 1 to the posterior right lateral part of the head (fig. 5). Two riders showed no signs of impact except minor abrasions from the chin-straps. One of the two helmets worn was obtained for examination. It was undamaged. All 6 cases showed varying degrees of disruption of the brain stem between pons and the oblonged medulla, or widespread haemorrhages in the nervous tissue. Disruption of all parasagittal bridging veins was found in 2 cases and in one case disruption of several such veins occurred. In 4 of the cases, there were no other injuries of importance except for the one which is under discussion at present.



- *Helmeted riders*
- *Riders without helmet*

Fig.5. Point of impact in 4 helmeted riders suffering disruption of the head-neck junction.

Injuries to the cervical spine without head injuries.

Among those 4 riders suffering from injuries of this type, one showed disruption of the transverse ligament of the axis. There were two cases of fracture of the odontoid process of the axis. One of these riders had been wearing an FF-helmet and one an OF-helmet. As a result of anteroflexion of the head 1 rider suffered an oblique fracture of the fourth cervical vertebral body. All riders in the group showed injuries to the cervical medulla. In 3 cases, the points of impact could be determined. In the case of the rider sustaining disruption of the transverse ligament of the axis and 1 of the riders suffering fracture of the odontoid process of the axis the point of impact was the anterior part of the head and for the latter rider the point of impact was the upper posterior part of his head.

Injuries of the cervical spine concomitant with head injuries.

Among those riders with head injuries already mentioned, there were 10 cases suffering from cervical spine injuries as well. Minor haemorrhages were found in the vicinity of C I in 3 cases and in 1 case in the vicinity of C II - C III. The remaining 6 cases showed tears of the intervertebral discs or disruption of the longitudinal ligament. In 4 cases, the level was C VII - Th I, in 1 case C VI - C VII and in 1 case C V - C VI. Macroscopic medullary injuries apart from minor leptomeningeal haemorrhages, were not found. Four of the 10 riders wore OF-helmets and 2 FF-helmets. Helmet wearing appears not to have played any decisive role in the occurrence of these types of injury.

DISCUSSION

Head and neck injuries are often suffered by mc and moped riders involved in accidents (Graham, 1969, Mätzsch, 1983). Therefore prevention by the use of helmets is obvious. The beneficial effect of protective helmets is also documented in statistical accident analyses (Watson et al., 1980, Heilman et al., 1982). For this reason, it is understandable that the use of preventive helmets is ratified in many countries.

Despite the use of helmets, there are still many serious and fatal head and neck injuries among mtwv riders owing to the great risk of head impact when riding mcs and mopeds. An study in depth of the head and neck injuries occurring in accidents would seem to be a logical point of departure when looking for better helmet design. From a survey of the available literature on the subject only a few older studies of this kind were found (Cairns, 1941, Cairns and Holbourn, 1943). A thorough knowledge of all injuries is essential for such an analysis. Contrary to clinical investigations of survivors, where there are difficulties in determining certain injuries e.g. fractures of the skull (Webber and Folio, 1976), autopsy material offers a good opportunity for carrying out such a study.

Head impact can result in injuries not only to the point of impact, but also in remote tissues e.g. the head-neck junction,

its surroundings or within the skull. Some injuries can be the result of angular acceleration like the disruption of parasagittal bridging veins (Voigt et al., 1977). The origin of some injuries e.g. cortical contusions is not fully known.

The head and neck injuries presented in this study were sub-grouped in the following manner: 1. injuries to the head at the point of impact and 2. injuries to the head and neck remote from the point of impact. Forty-four of the 64 riders suffering injuries to the point of impact were helmeted. Among those 62 riders where the point of impact could be determined, in 20 cases the point of impact was the anterior part of the head. In 42 cases the point of impact was the lateral or posterior part of the head. The points of impacts were mostly distributed within a hat-band like zone around the head. Consequently, this is where the helmets must offer a better degree of resistance. The protective function of the helmets is accomplished by force distribution (shell) and energy absorption (lining). The numerous cases of injuries to the point of impact show the limitations of today's helmets.

The following injuries remote from the point of impact were found: 1. Intracranial injuries without fractures (central cerebral haemorrhages, disruption of parasagittal bridging veins and what are referred to as gliding contusions), 2. Ring fractures of the base of the skull, 3. Disruption of the head-neck junction, 4. Injuries to the cervical spine without head injuries. With reference to the points of impact, the injuries found are listed in table 1.

TABLE 1 Injuries to the head and neck remote from the point of impact listed with reference to the direction of the impact.

Anterior part of the head	14	intracranial injuries without fractures (13 helmeted)
	9	ring fractures of the base of the skull (8 helmeted)
	3	disruptions of the head-neck junction (all helmeted)
	2	injuries to the cervical spine without head injuries (1 helmeted)
Lateral-posterior part of the head	1	intracranial injury without fractures (helmeted)
	8	ring fractures of the base of the skull (5 helmeted)
	1	disruption of the head-neck junction (helmeted)
	1	injury to the cervical spine without head injury (helmeted)

The distribution of the impact direction differs considerably between the injuries to the point of impact as against the injuries remote from the the point of impact. In the latter group, the point of impact was most often the anterior part of the head. When impacted frontally, the head is probably thrown backwards. This agrees with the opinion that most of these

injuries are readily explained by angular acceleration in an anterior-posterior direction (Voigt et al., 1977).

Three riders suffering ring fractures of the base of the skull and 2 riders suffering disruption of the head-neck junction showed no signs of impact to the head except minor abrasions from the chin-strap or the helmet-edge. The point of impact might have been the head but it is also possible that these injuries are the result of a centripetal movement owing to decreased velocity of the body in relation to the head.

It has been shown that injuries to the point of impact can be prevented by helmets (Carr et al., 1981). As to injuries remote from the point of impact the effect of the helmet is doubtful. However, the results from earlier investigations (Huston and Sears, 1981) show that the mass of the helmet decreases the angular acceleration and thus might diminish the risk of such injuries as disruption of the parasagittal bridging veins.

No type of injury was specific for the helmeted riders except for the finding that all of those with disruption of the head-neck junction (6 riders) were helmeted. Seventeen riders of the 21 riders suffering ring fractures of the base of the skull were helmeted (11 FF-helmet). It should be emphasized that this type of injury was found mostly among mc riders (15 out of 21) who were helmeted in all cases but two and used an FF-helmet in 37 cases out of 69. The type of accident and consequently the impact forces probably differ greatly in accidents involving motorcycles or mopeds. As 30 of the 32 riders without helmets were moped riders, it is impossible to compare the injuries suffered by helmeted and unhelmeted riders unconditionally. From the finding that all of the riders suffering disruption of the head-neck junction were helmeted and that a large number of helmeted riders suffered ring fractures of the base of the skull, it may yet be assumed that the 20% increase of the total mass of the head, caused by the helmet, does contribute to these injuries. The hazard of helmet-induced injuries has only briefly been touched upon by a few authors (Davydov and Nirenburg, 1978, Sorgo, 1978, Aldman et al., 1979, Hurt, 1979, Huston and Sears, 1981). In an experimental study, Krantz and Löwenhielm (1984) showed that increased helmet mass will produce a higher traction force in the head-neck junction when the head receives a lateral blow. This result is probably valid also when the head receives a frontal blow.

This study shows that the head injuries often sustained by killed mtwv-riders are the result of a head impact of such magnitude that the helmet was unable to provide protection from injury at the point of impact. In many cases the point of impact was the face where the helmet-lining offers no absorption of the energy. A surprisingly high number of injuries were found remote from the point of impact. Almost half of the persons suffered such injuries. Sixteen percent sustained ring fractures of the base of the skull, a frequency twice as great ($p < 0.001$, χ^2 11.778, 1 d.f.) as the frequency among killed car occupants (Krantz and Löwenhielm, 1980). There were few

fractures of the cervical spine among the mtwv-riders. This indicates other mechanisms for the origin of these injuries among the mtwv-riders compared with other road users. Considering cases with injuries remote from the point of impact, the protective effect of the helmet is doubtful. It seems possible that the use of helmets in cases of head impact transfers the injuries from the point of impact to other parts of the head and neck. Even though helmet use might slightly decrease the risk of disruption of parasagittal bridging veins, it is likely that the helmet contribute to deleterious injuries to the head-neck junction.

According to the results of this study helmets should be more resistant to impact, give a better protection to the face and absorb more impact energy. However, such improvements must not entail an increase in helmet mass. This would only result in injuries being transferred from the point of impact to the fragile structures in the vicinity of the head-neck junction.

References:

- Aldman B. et al., (1979) The protective effect of crash helmet-sa study of 96 motorcycle accidents. Proc.IV Int. IRCOBI Conf. Göteborg, 63.
- Cairns H. (1941) Head injuries in motor-cyclists. Br. Med. J. 2, 4213.
- Cairns H., Holbourn H. (1943) Head injuries in motor-cyclists with special reference to crash helmets. Br. Med. J. 4, 591.
- Carr W.P., Brandt D., Swanson K. (1981) Injury patterns and helmet effectiveness among hospitalized motorcyclists. Minn. Med. 64, 521.
- Davydov E.A., Nirenburg R.K. (1978) The effect of protective helmets and head guards on damage to the skull and brain in craniocerebral trauma. Zh. Vopr. Neirokir. 5, 13.
- Drysdale W.F. et al. (1975) Injury patterns in motorcycle collisions. J. Trauma 15, 99.
- Graham J.W. (1969) Fatal motorcycle accidents. J. For. Sci. 14, 79.
- Heilman D.R. et al. (1982) Motorcycle-related trauma and helmet useage in north Dakota. Ann. Emerg. Med. 11, 659.
- Hurt H.H. (1979) Motorcycle accidents cause factors. DOT-HS-5-01160.
- Huston R.L., Sears J. (1981) Effect of protective helmet mass on head/neck dynamics. J. Biomech. Ing. 103, 18.

Krantz, P., Löwenhielm P. (1980) Injury response in belted and unbelted car occupants related to the car crash energy in 458 accidents. Proc. V Int. IRCOBI Conf. Birmingham, 305.

Krantz, K.P.G., Löwenhielm C.G.P. (1984) Effect of protective helmet mass on neck axial force in head impact. Submitted to J. Biomech. Eng.

Mätzsch T. (1983) Injuries in moped- and motorcycle accidents - a five-year-series. Läkartidn. 80, 2514.

Sorgo, G. (1978) Neue Erkenntnisse bei der Verwendung des Sturzhelms. Beitr. Ger. Med. 36, 395.

Voigt G.E., Saldeen, T. (1968) Ueber den Abriss zahlreicher oder sämtlicher Vv. cerebri sup. mit geringem Subduralhaematom und Hirnstammläsion. Dtsch. Z. ges. gerichtl. Med. 64, 9.

Voigt G.E., Sköld G. (1974) Ring fractures of the base of the skull. Trauma 14, 494.

Voigt G.E., Löwenhielm C.G.P., Ljung C.B.A. (1977) Rotational cerebral injuries near the superior margin of the brain. Act. Neuropat. 39, 201.

Watson G.S., Zador P.L., Wilks A. (1980) The repeal of helmet use laws and increased motorcyclist mortality in the United States, 1975 - 1978. Am. J. Public Health 70, 579.

Webber R.L., Folio J. (1976) Radiographic detectability of occipital and temporal-parietal fractures induced in cadaver heads. J. Trauma 16, 115.

Effect of Protective Helmet Mass on Neck Axial Force in Head Impact

by

K. Peter G. Krantz and C.G. Peter Löwenhielm

Abstract

In a consecutive series of fatal moped and motorcycle accidents in southern Sweden, disruption of the atlanto-occipital joint was found only in persons wearing protective helmets. Ring fractures of the base of the skull were also common. In order to determine if the helmet mass influences on the stresses in the neck following head impact, tests were performed with a helmeted dummy head. Increased helmet mass was found to increase the axial force in the neck, i.e. an increased risk of injuries to the head-neck junction. Tests with polycarbonate termoplastic shells resulted in higher axial neck force compared with glass fibre reinforced polyester shells which are stiffer. This finding is interpreted as a "grounding" of the less stiff polycarbonate shell with the unyielding dummy head.

Introduction

Skull and brain injuries are the dominating types of injury suffered by moped-riders and motor-cyclists involved in accidents and demand protective measures. The beneficial effects of protective helmets are well documented (1,2). Compulsory helmet use was legislated in 1978 in Sweden. After this date the frequency and the severity of skull/brain injuries have decreased (3). Luna et al (4) have shown that the risk of neurologic injury is tripled in motor-cyclists not wearing protective helmets. In a prospective study (5) of moped and motor-cycle accidents with fatal outcome (132 cases) in southern Sweden, disruption of the atlanto-occipital joint was seen only in those riders who had used protective helmets (6 cases of 102). Ring fractures were also quite common and observed in a significantly higher frequency compared with killed automobile occupants. By those results, the mass of protective helmets can be supposed to contribute to injuries to the head-neck junction.

American helmet standards demand high resistance to penetration of the helmet shell. This is why American protective helmets have a thicker helmet shell and in consequence a higher helmet mass compared with European helmets. Present standardization work aims at coordinating American and European standards. If, a standard like the American one is adopted, the helmet mass will necessarily be increased. An investigation regarding the potential deleterious effects of

the helmet mass in traumatically induced head movement was considered necessary. For this purpose, neck forces as a function of varying helmet mass were studied by way of dummy experiments.

Material and methods

The experimental set-up used is apparent from figure 1. A wooden dummy head (about 5 kg) was linked to a stiff dummy trunk (about 28 kg) with an inter-connecting force transducer. The force transmitted through the neck was registered by means of the force transducer which was equipped with strain gauges and permitted recording of the force in three directions. The dummy trunk was linked together with the floor. The dummy head could be impacted with a pneumatic impact cylinder (Martonair M/3082). The impact cylinder was equipped with an accelerometer (Endevco 723/C-750) and the impact speed was calculated from the impact cylinder acceleration record. All the tests were performed under similar conditions, i.e. the same test geometry of the dummy and the same impact speed except for one group of helmets (cf. table 1, group 5). The different helmet types used are apparent from table 1. The initial position of the dummy head was about 15° attitude to the horizontal plane and the impact was directed through the center of gravity of the dummy head. The helmets were tested from the right side as well as from the left side giving a mirror view test situation and enabling the use of the same helmet twice. The impact force was recorded by means of a piezoelectric force transducer (Kistler 9031).

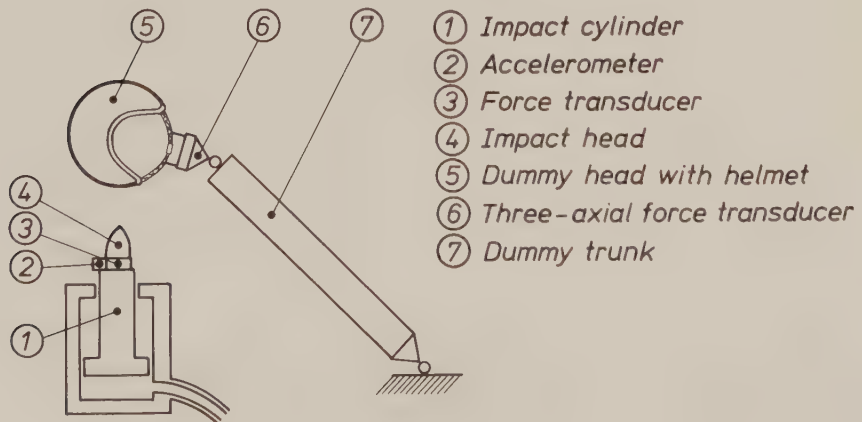


Fig. 1 Experimental model

In an attempt to significantly reduce the mass, tests without helmets were also performed. In these instances, the dummy head was equipped with a piece of helmet shell and lining material (approximately 5 x 10 cm) to mimic the impact conditions of the helmet tests. From table 1 it is apparent that the helmets with glass fibre reinforced shells have a larger mass variation than the helmets with polycarbonate shells. This difference is caused by the considerable variation in thickness of the glass fibre reinforced shells which are manufactured with a larger proportion of manual work.

In order to get a conception of the stiffness of the shell materials two helmets of the same design were tested in side-to-side compression. One helmet had a polycarbonate shell, the other one had a glass fibre reinforced shell.

Table 1 Types of protective helmets used

Group	Make	Type	Shell material	Weight (grams)	Number of tests
1	Yes	FULL FACE	Glassfibre reinforced polyester	1348 [±] 35	10
2	Boeri	FULL FACE	Glassfibre reinforced polyester	1152 [±] 41	10
3	Boeri	OPEN FACE	Polycarbonate termoplastic	738 [±] 11	10
4	Tommy	OPEN FACE	Polycarbonate termoplastic	876 [±] 8	6
5a	Nolan	FULL FACE	Glassfibre reinforced polyester	1495 [±] 49	4
5b	Nolan	FULL FACE	Polycarbonate termoplastic	1225 [±] 7	4

Results and discussion

The general design of protective helmets for moped riders and motorcyclists is a helmet with an outer hard shell with a thickness of about 4 mm and an interior lining of varying thickness (20-30 mm). The function of the shell is to distribute the force while that of the lining is to absorb the energy by deformation. The materials of the shells are usually glass fibre reinforced polyester (GF) or polycarbonate (PC) or acetyl butadiene styrene (ABS) termoplastics. The lining is almost always made of expanded polystyrene (EPS).

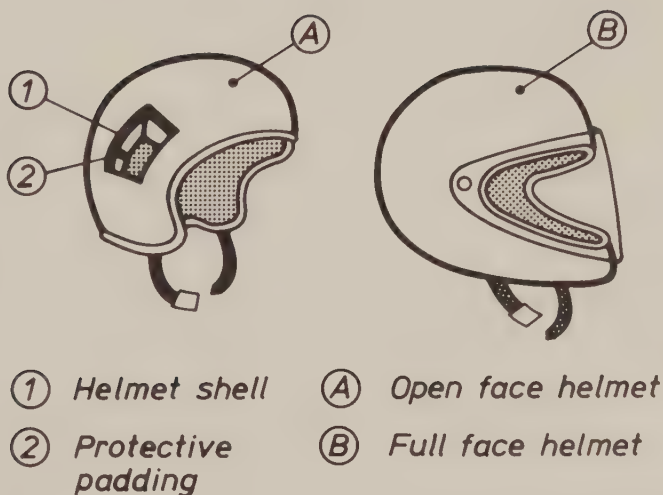


Fig. 2 Schematic design of open face helmet and full face helmet

There are two main types of protective helmets: the open face (OF) helmet and the full face (FF) helmet, which has a chin protecting part (cf. figure 2). The shells of the helmets tested in the present series were either made of polycarbonate termoplastic or of glassfibre reinforced polyester.

The impact speed ranged from 4.2 - 4.4 m/s. This corresponds to a speed which is reached after a free fall from about one meter. The distance between the head and the ground for a moped-rider or a motor-cyclist is about 1.2 - 1.3 meters.

The experimental test geometry was chosen quite arbitrarily. It should be emphasized, though, that the site of impact is often situated within a zone around the head in a real life accident situation (compare the sweat-band of a hat). Thus, the impact site chosen in the present experiments (towards the side of the head) has a real counterpart.

The results of the side-to-side compression tests are presented in figure 3. The stiffness of the GF-helmet is almost twice that of the PC-helmets.

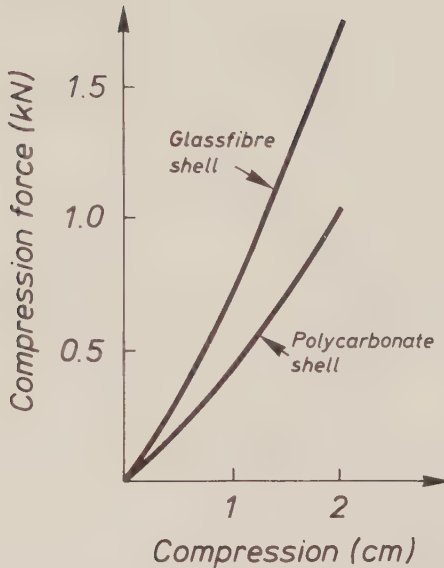


Fig. 3 Glassfibre reinforced polyester shell and polycarbonate thermoplastic shell stiffness in side to side compression.

In the experiments the GF-helmets had a tendency to crack at the impact site while the PC-helmets only exhibited minor permanent indentations. The peak value of the impact force differed considerably between the two helmet types. In figures 4 and 5, impact force - time - histories are presented. For the OF-helmets with PC-shells, the peak force value was about 7.8 kN and for the FF-helmets with GF-shells about 4.0 kN. In all the tests, the contact time of the helmet impact was relatively constant, about 25 ms. The impulse transmitted during the impact gave the head-helmet system a momentum of approximately 49 Ns for the OF-helmets with PC-shells and about 50 Ns for FF-helmets with GF-shells. The momentum was calculated as $\int F dt$. The difference in momentum is negligible and the tests were considered performed under constant external conditions.

From figures 4 and 5, it is apparent that there is a considerable difference in the peak value of the impact forces. Considerably higher forces were obtained for the OF helmets with PC-shells than for the FF-helmets with GF-shells. In order to find out, whether this difference was caused by the material of the helmet shell or if it rather was the design of the helmet that caused the difference, two FF-helmet types, one with PC-shell and the other type with GF-shell were tested. The impact force magnitude in these experiments

is apparent from figure 6. The type and design of the helmet in these tests are comparable, while the difference in the material of the shell caused some difference in mass. The two graphs exhibit a good correspondence with the graphs in figures 4 and 5. Consequently, the high force peaks in figures 4 and 6 must be regarded as an effect of the shell material.

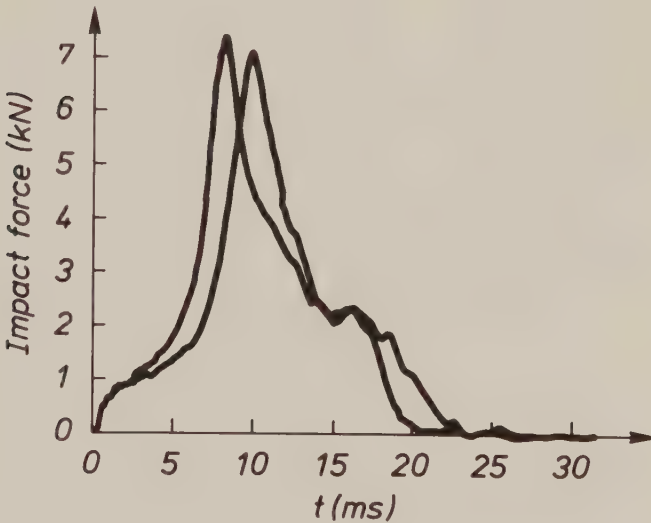


Fig. 4 Impact force-time-histories for OF-helmets with PC-shells.

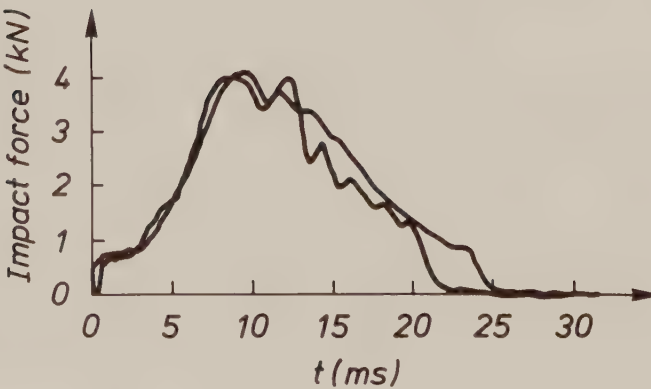


Fig. 5 Impact force-time-histories for FF-helmets with GF-shells.

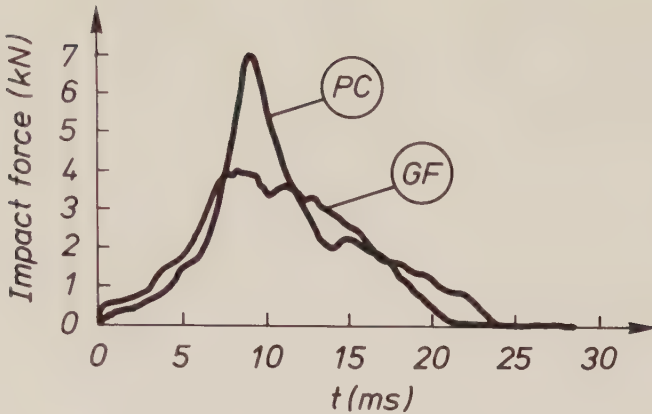


Fig. 6 Impact force-time-histories for FF-helmets with PC- and GF-shells.

The duration of the peak of the impact force for helmets with shells made of polycarbonate is about 5 ms. At a speed of about 4 m/s the impact cylinder head moves about 20 mm. The side to side compression tests (cf. figure 3) imply that a higher yielding capability of PC may contribute to greater local deformation of the helmet and consequently the pronounced peak of the impact force may be an effect of grounding of the shell onto the unyielding dummy head. In the same manner, this high peak suggests an increased risk for linear skull fractures, impression fractures or intracranial injuries.

Typical time-histories for the axial force in the dummy neck are apparent from figures 7 and 8. The time-histories for the axial force are average values for each helmet type. Within each group, the force-time-histories differ very little. Hence, each helmet type has its own characteristics. This is apparent from the two force-time-histories in figure 8, where the two helmet types differ only in shell materials. As the two graphs exhibit the same details, it can be assumed that the typical time-history for the different helmet types regarding the axial force in the neck is caused by the design of the helmet rather than by the material of the shell. This result is contrary to that obtained for the impact force where the time-history is dependant on the material of the shell (cf. figure 6).

The results presented in figure 9 - the axial force in the neck versus the helmet mass - show that the force in the neck (the peak value of the axial force after impact to the helmet) increases with increasing helmet mass. In this context, special attention has been paid to the type of helmet and the type of shell material. An OF-helmet with PC-shell gives a higher average of the axial force in the neck

than an FF-helmet with a GF-shell. The difference in magnitude for the two helmet types (OF-PC-helmet and FF-GF-helmet) can be assumed to be an effect of the helmet material. As has been mentioned above, the lower stiffness of the PC-shells results in higher peak magnitude of the impact force (compare figures 4, 5 and 6). This assumption is further validated by the tests with helmets of the same designs but with different materials of the shells. From figure 8, it is apparent that the peak value for the axial force in the neck is of the same order of magnitude. The weight of the GF-helmet is about 250 grams higher than that of the PC-helmet. For the PC-helmet this weight difference should have produced a lower peak value for the axial force in the neck but with maintained characteristics of the force-time-history. However, this effect is reduced by the lower stiffness of the PC-shell with subsequent higher peak impact force caused by the shell grounding onto the hard dummy head. As mentioned above, tests with these helmets (group 5a and b, cf. table 1) were performed at somewhat lower impact speeds and therefore the results cannot be compared with the results for the groups 1-4.

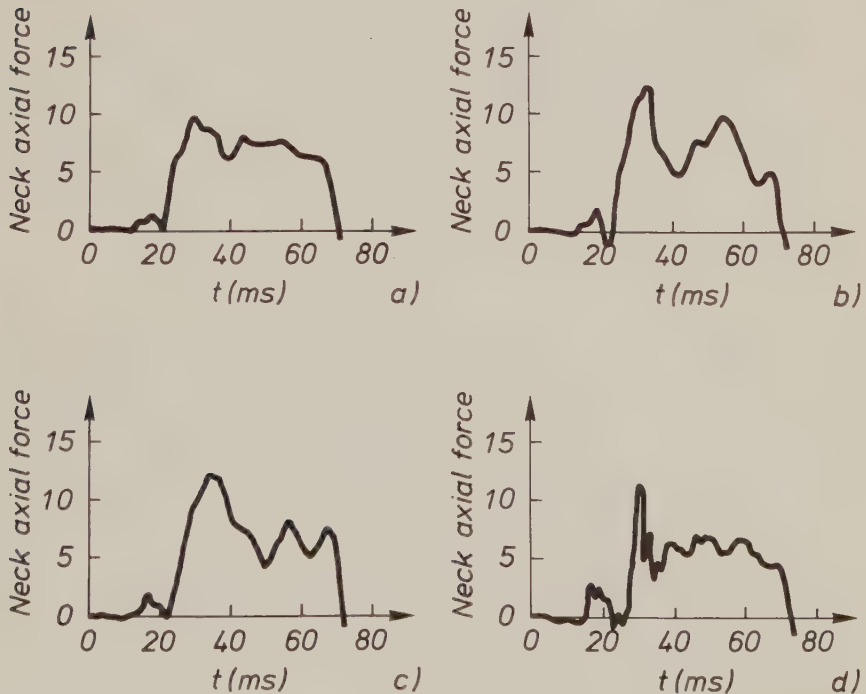


Fig. 7 Neck axial force-time-histories for the helmet types used.
a: Boeri FF-GF-helmet, b: Yes FF-GF-helmet,
c: Boeri OF-PC-helmet, d: Tommy OF-PC-helmet.

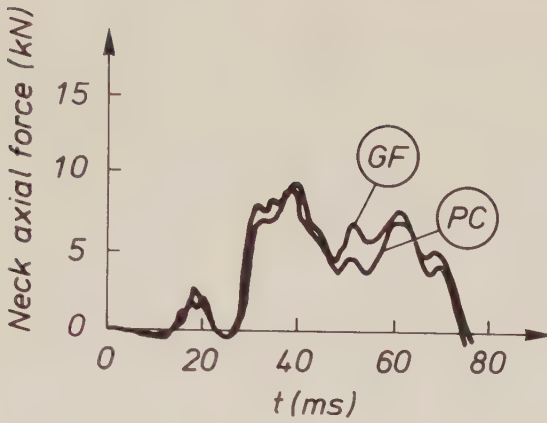


Fig. 8 Neck axial force-time-histories for Nolan FF-helmets with PC- and GF-shells.

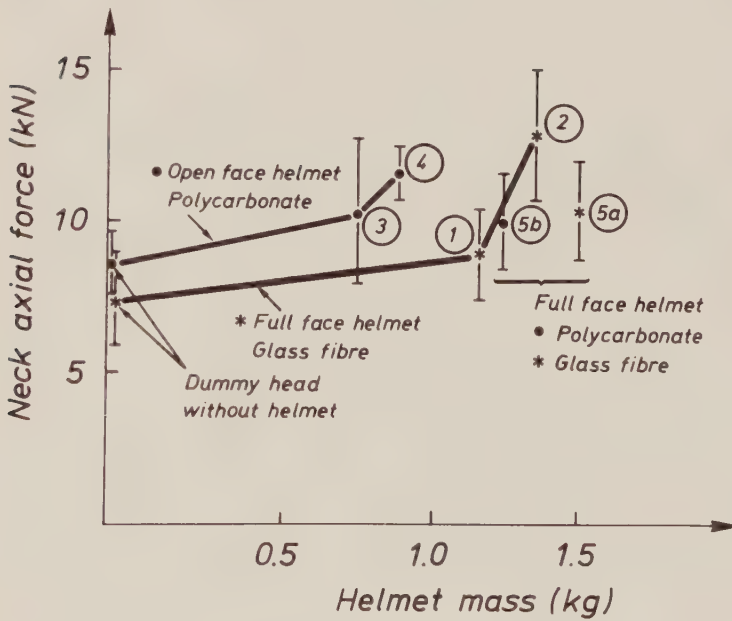


Fig. 9 Mean value of peak axial force in the neck. Numbers in circles refer to the helmet types presented in table 1. 1 - 4 tested under similar impact conditions. 5a and 5b tested at a somewhat lower impact speed.

There has been considerable discussion if the crash helmet can contribute to injury in a "whip-lash" situation. By using a computer simulation model, Huston (6) studied the potential deleterious effects of the helmet mass and inertia through increased head rotations during high acceleration periods. Indeed, a heavy helmet yields a greater head angular rotation compared with a head without a helmet. However, the peak head angular acceleration and peak head angular velocity were slightly decreased by the helmet mass. Löwenhielm (7) has proposed tolerance levels for disruption of the parasagittal bridging vein: a critical peak angular acceleration and a critical angular velocity change must be exceeded at the same time before bridging vein disruption is likely to occur. Consequently, it can be assumed that increased helmet mass does not increase the risk of disruption of the parasagittal bridging vein, although a heavy helmet might contribute to hyperextension or hyperflexion injuries to the cervical spine. However, the magnitude of head angular acceleration and change of head angular velocity may be influenced by the quality of the surface of the shell (8). In the present series of tests, the impact direction was chosen such that sliding effects, which may also contribute to forces in the neck, were avoided.

Unterharnscheidt (9) has presented a study on a carefully controlled series of experiments with whole body $-G_x$ impact acceleration exposures of Rhesus monkeys with completely restrained torsos but unrestrained head and neck. The head and neck underwent flexion during the experiments. If the peak acceleration was high enough injuries were obtained at the region of the atlanto-occipital joint with disruption of the transverse and proximal parts of cruciate ligaments with traumatic transection of the spinal cord. One of the mechanisms made responsible for head neck failure is stretch along the longitudinal axis of the neck. The experimental set-up in Unterharnscheidt's investigation mimics in great detail the geometry of the mathematical simulation of neck injuries presented by Reber and Goldsmith (10). Their investigation shows that axial loading of the head and neck junction is an important parameter even though shear forces may contribute to injuries to the structures at this level. In the present investigation, the transverse components of the neck forces recorded with the three-axial force transducer were of a smaller magnitude compared with the axial component in the experimental situation used.

Conclusions:

An increased helmet mass increases the axial force in the neck when the dummy head is hit from the side and thereby indicates an increased risk of injuries to the head-neck junction, e.g. atlanto-occipital disruption and traction ring fractures of the base of the skull.

The material of the helmet shells influenced the magnitude of the peak axial force in the neck and the peak impact force in side impact to the dummy head. Impacts to helmet shells made of polycarbonate resulted in higher peak forces compared with impacts to glassfibre reinforced shells. These results are interpreted as a more pronounced grounding of the less stiff polycarbonate shells with the unyielding dummy head.

References

1. Reich, H., Dalgaard, J.B., Hätte ein Stürzhelm den Tod verhindern können? Z. Rechtsmedizin Vol. 75, 1975, pp. 235-239.
2. Watson, G.S. et al., Helmet use, Helmet use laws, and motorcycle fatalities. Am. J. Public Health Vol. 71, 1981, pp. 297-300.
3. Engström, A., Causes and consequences of moped and motorcycle accidents. Scand. J. Soc. Med. 1979 suppl. 15.
4. Luna, G.K. et al., Motorcycle helmets: nonuse multiples risk of neurologic injury. West. J. Med. Vol. 135. 1981, pp. 89-92.
5. Krantz, P. Protective helmet influence on head and neck injuries in mc- and moped-riders. (Submitted to Injury).
6. Huston, R.C., Sears, J., Effect of protective helmet mass on head&neck dynamics. J. of Biomechanical engineering Vol. 103. 1981, pp. 18-23.
7. Löwenhielm, C.G.P., Strain tolerance of the vv. cerebri sup. bridging veins calculated from head-on collision tests with cadavers. Z. Rechtsmedizin Vol. 75, 1974, pp. 131-144.
8. Glaister, D.H., The development and initial evaluation of an oblique-impact test for protective helmets AGARD-CP-322, Conference Proceedings pp. 33-1 - 33-8, Cologne, April 26-29, 1982.
9. Unterharnscheidt, F., Neuropathology of the rhesus monkey undergoing $-G_x$ impact acceleration Preprint AGARD Conference proceedings. Cologne, April 28-29 (1982).
10. Reber, J.G., Goldsmith, W., Analysis of large head-neck motions J. Biomechanics Vol. 12, 1979, pp. 211-222.

